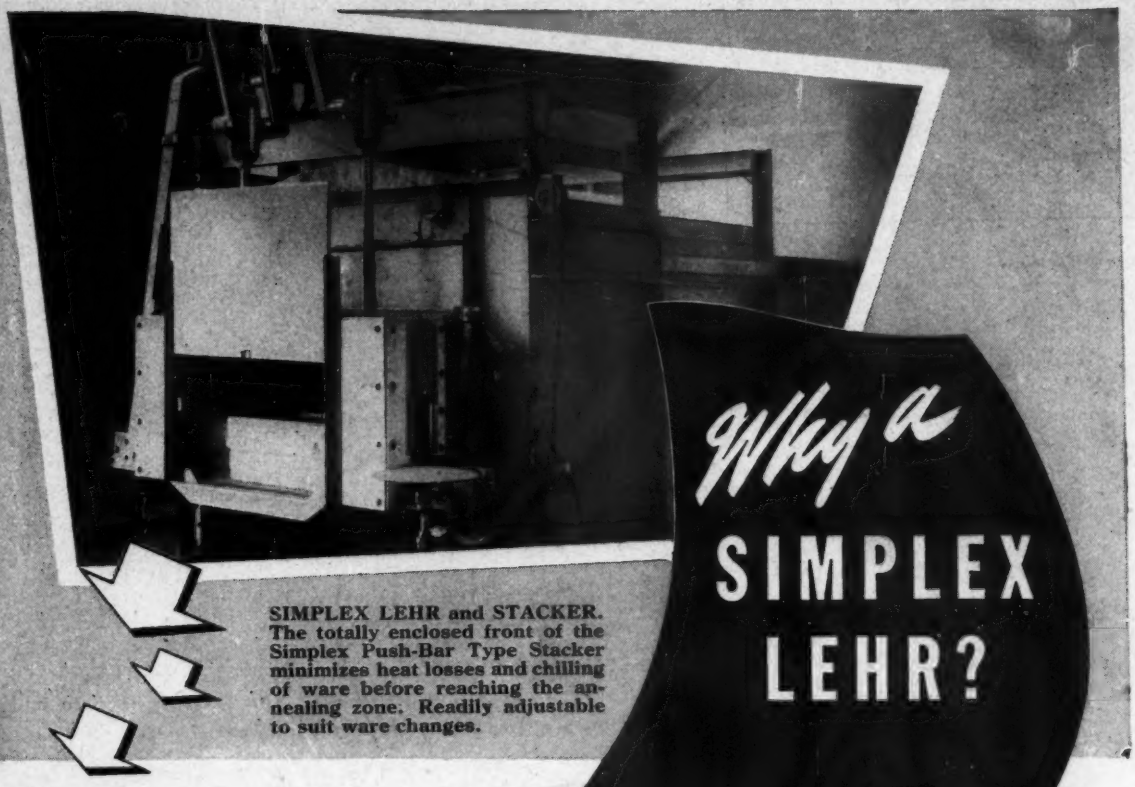

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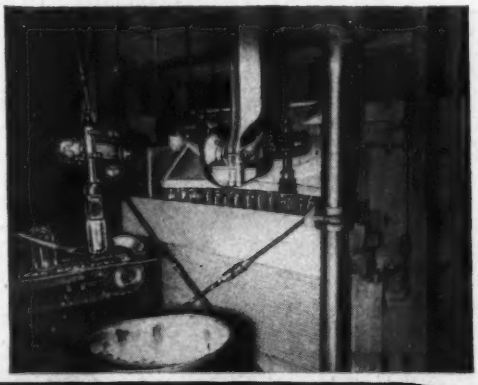

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CONTENTS FOR JANUARY : 1946

Mechanical Strength of Glass, Part I ... ...

The first installment of a paper which discusses the various factors affecting the mechanical strength of glass.
W. A. Weyl

Glass Container Manufacturers Institute Meets in Miami ... ...

Nine standing committees of Glass Container Manufacturers Institute report to membership at first semi-annual meeting.

The Welding of Glass to Metal ... ...

A brief account of research and development carried on in Great Britain with regard to the welding of glass to metal.
E. M. S. Wood

Inventions and Inventors ... ...

Summary of Recently Issued Patents of Interest to the Glass Industry.

Research Digest ... ...

Practical Interpretations of Glass Technology.

Current Statistics ... ...

Production, Shipments and Employment for the months of October and November.

New Equipment and Supplies ... ...

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THE GLASS INDUSTRY

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THE MECHANICAL STRENGTH OF GLASS

By W. A. WEYL*

Glass Science, State College, Pa.

PART I

Editor's Note: Since the publication of this paper must be extended over a period of several months due to the volume of material developed by Dr. Weyl, it is felt that in addition to the brief abstract included in this installment, the following chapter outline of the complete article would be desirable.

I. Abstract. II. Introduction; some features of the strength of glass which seemed both puzzling and unique; 1. The shape factor, 2. The time factor, 3. The role of the environment, 4. The influence of the temperature, 5. The influence of the previous heat treatment. III. Fundamentals concerning the tensile strength of glass; 1. The molecular process of fracture, 2. Tensile strength, a "structure sensitive" property, 3. The role of flaws, 4. The influence of temperature on the tensile strength, 5. The influence of the duration of the load on the strength value, 6. The influence of the environment on the strength of glass, 7. The influence of a surface layer prestressed under compression. IV. Formulation of a basis for comparing the strength of glass with that of other materials; 1. The tensile strength of glass as compared with that of organic polymers, 2. The "Fatigue" of glass as compared with other "Chemical Fatigue" phenomena, 3. The tensile strength of glass as compared with the fatigue strength of metals, 4. The tensile strength of "toughened" glass as compared with the fatigue of metals prestressed under compression. V. Possibilities of increasing the strength of matter by prestressing the surface under compression. VI. The "anomalous" strength of glass fibers. VII. The hardness of glass. VIII. Summary and conclusions.

I. Abstract

The mechanical strength of all solids is far below the value which one would expect from the chemical or electrical forces holding their atoms together. This discrepancy is due to spots of exceptional weakness, such as lattice defects, flaws, and surface cracks, which exist in the structures of all solids, crystalline or amorphous. The influence of surface flaws predominates; this is especially true when a material is tested under conditions where the environment can enter a chemical reaction with the material and thus contribute to separating the atoms. In this case failure occurs under the combined effort of mechanical tension and chemical reaction (corrosion), both breaking the bonds which hold the ions together.

The tensile strength of glass can be compared with that of other materials, such as metals, plastics or rubber, only if they are tested under conditions where their flaws and their environment exercise comparable influences.

In this paper a basis is presented on which the strength properties of metals, glasses and plastics can be compared.

It is known that the static strength of glass and the fatigue endurance of metals can be improved by prestressing the surface layer under compression. The theory of this phenomenon is discussed and a survey was made over the existing methods which accomplish this aim.

II. Introduction: Some Fentures of the Strength of Glass Which Seemed Both Puzzling and Unique

Sometimes in our search for a better understanding of the properties of glass, we come to a problem which offers exceptional difficulties. Then we do well to look around for similar problems in neighboring fields. The chances are that one of our fellow scientists has found a solution for his problem, and we may benefit from his experience. To the initiated the properties of glass offer numerous examples, where concepts used in other fields, such as crystallography, mineralogy or geology, have furthered our understanding. The atomic structure of glasses has been elucidated by the advances made in the crystal structures of silicate minerals. The light absorption of colored glasses and the interaction of coloring agents became understood only when they were correlated with those of aqueous and non-aqueous solutions. Optical, chemical and electrical properties of

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glasses have always been compared with those of other materials, crystalline or liquid. Only the problems centering around the mechanical strength of glass could not be solved by such treatment. So far, all efforts to correlate the mechanical behavior of glass with that of other solids, e.g., of metals, seem to have failed.

This is particularly surprising because the mechanical strength should be one of the simplest properties of matter. It deals with the force which has to be applied to separate the atoms or ions far enough so that their mutual attraction is overcome. For crystalline materials such as metals, the problem becomes more involved because the forces between the atoms are functions of the crystallographic orientations. Furthermore, most metals consist of a variety of crystals, so that the strength of the bond between different crystals has to be taken into consideration. Glasses, however, should show none of these complications and their mechanical strength should lend itself more readily to a theoretical treatment than do metals and alloys. The properties of glasses are independent of the direction in which they are measured; glasses are isotropic and homogeneous, and the forces acting between their atoms invite statistical treatment.

There is, however, one factor to bear in mind when correlating the mechanical strength and that of the chemical bonds. Failure of a material under tension is, as a rule, not the result of an external field of force overcoming the average interatomic attraction, but that of excessive stresses accumulating at certain weak spots in the structure. The mechanical strength is a "structure sensitive" property.

All solids have in common the phenomenon that their mechanical strength is only a small fraction of that value which one would expect, judging from the strength of the bonds which hold the atoms together and whose value may be determined from the heat of formation. The mechanical strength of a material, therefore, does not provide insight into the forces acting between the atoms proper, but merely reflects the behavior of certain flaws, lattice imperfections and surface scratches under tension. In this respect there is no difference between crystalline and amorphous solids, a fact which has been established through the work of Griffith, Joffee, Smekal, Orowan and others.

If we accept the picture that the flaws dominate the behavior of matter, and that the average energy required to separate two atoms is only of secondary importance, we must attribute the differences in the strength properties to different reactions of various materials to their flaws rather than to major differences in chemical bond strength. That means, if we find that the strength properties of metals or certain plastics differ principally from those of glass, we should not look at their interatomic or intermolecular forces for an explanation, but investigate why the flaws present in their structures exert different influences when brought under tension.

It will be seen from this paper that the apparently fundamental differences between metals and glasses, so far as their mechanical strength is concerned, disappear if these materials are tested under conditions where they react alike in respect to their flaws. Keeping this in mind one can find a common basis on which to discuss the strength of glasses, metals and organic materials.

Before doing so, let us briefly review some facts which are responsible for the widespread opinion that the strength properties of glasses are both erratic and unique, and principally different from those of other materials.

1. The shape factor. One way to measure the strength of a material is to determine the load which a rod of a certain cross section carries. We know then, within certain limits, that another rod made from the same material but having a ten times larger cross section can also carry the tenfold load. This linear relation between load and cross sectional area does not seem to exist for glasses. The thinnest glass fibers ever made were found to carry a load of nearly 1,000,000 lbs./sq. inch, that is about one hundred times more than would be expected from strength tests made with thicker rods. The strength of glass varies with the cross section. It seems that the tensile strength is not a property inherent to the material but rather depends on the shape.

It is true that similar phenomena have also been observed with other materials, such as metals and rubber. In this case, however, an explanation could be given based on the orientation of the crystals. Rubber when stretched changes from the amorphous into a crystalline state with the crystals oriented in the direction of stretching. Both states can be easily frozen in by cooling the rubber to low temperatures. According to M. Polanyi and A. Schob,[1] the tensile strength of native rubber increases about five times when stretched to ten times its original length. This phenomenon is well understood; the change in the structure accounts for the difference in the properties. All efforts to prove experimentally a similar orientation effect in glass fibers have failed so far.

Since the early observations of Threlfall[2] and the classical research of Griffith[5] on the strength of fibers, glass technologists were puzzled by this abnormal cross sectional area-strength relationship. In view of these facts, F. W. Preston[4] introduced the term "surface strength" for glass. His function is based on the concepts that the strength of glass fibers is proportional to the cross sectional area, but is inversely proportional to the surface area under tension.

The weakening effect of the surface area under tension is responsible for the variation in strength if samples of different sizes are tested by the same method. It is also responsible for the different values obtained with one shape of test specimen when different methods are used. Bringing a glass rod under tension by applying a load affects its total surface. Bending the same rod brings only a small surface area under tension.

2. The time factor. The strength not only varies with the shape of the test piece, but also with the duration of the test. For short periods, glasses support loads which are three to four times greater than those which they can support for longer times. A similar phenomenon is also known for certain metals, but in this case the metals undergo a slow change (creep) which increases the deflection or elongation and decreases the cross sectional area. Glasses are free of creep; they obtain their full deformation shortly after the application of the load. Their decline in strength with the passage of time (fatigue of glasses) is principally different from that of a metal subjected to a creep test.

J. Bailey[5] showed that it is possible, at least to a certain extent, to correlate some of the data on the tensile strength of commercial glasses by taking into account the rate with which the load has been applied and the relation between the area under tension and the flaw distribution.

3. The role of the environment. The environment of the glass represents another factor which impairs the significance of strength tests. A fiber tested in vacuo is stronger than one exposed to air. Fibers immersed in paraffin oil exhibit greater strength than those immersed in water. The strength of a freshly drawn glass fiber decreases gradually with time, but it deteriorates rapidly when touched with the finger.

The glass blower who has to cut glass tubings takes advantage of this phenomenon by moistening the fresh cut before breaking the tube by a combined pulling and bending movement.

4. Influence of the temperature. There are well founded reasons why the strength of matter decreases with increasing temperature. The probability of a pair of atoms becoming permanently separated under the influence of tension increases with increasing thermal motion.

Temperature speeds up those elementary processes which cause a molecular crack to propagate. Well annealed glasses, however, are an exception; their strength increases noticeably when brought from room temperature to about 500°C. At higher temperature, of course, they deform due to viscous flow and fail in a way similar to metals in the creep test.

5. The influence of the previous heat treatment. The strength properties of a glass which had been chilled from red glow by a sudden air blast or by immersing it in oil have undergone a drastic change. The "Prince Ruppert Drop" and the "Bologna Flask" are well known examples. The latter is a little heavily walled bottle which as a result of having been chilled is highly stressed under compression at the outside and under tension at the inside. From the outside such a flask can stand up under the roughest treatment, but when scratched at the inner surface by dropping in a sharp sand grain, the bottle collapses. The compression stress toughens the glass, tension weakens it. There is no other material known besides glass where a mere heat treatment can bring about similar changes in the mechanical properties without an apparent change of structure.

These five factors: The influence of shape, temperature, time, environment and heat treatment on the strength of glass are chiefly responsible for such statements as, "The strength of glass is a mysterious quantity, and it is not clear upon which factors it depends" (F. W. Preston) or "We never test the strength of glass, all we test is the weakness of its surface" (J. T. Littleton). A few years ago, in his witty introduction to a characterized the problems by saying, "The mechanical properties of glass could be described in exactly the lecture on the mechanical properties of glass, Preston[6] same words as the famous treatise on the snakes of Ireland; namely, 'There are none!'"

Statements of this kind make interesting reading and may be suitable to catch the attention of the audience, but they are not very helpful to a teacher who wants to give his students a coherent picture of the mechanical properties of glass. A research worker who accepts these statements without criticism finds himself in an even more serious position; he becomes an isolationist who neglects to study the strength properties of metals and plastics, and thus misses the opportunity to benefit from the experience of his fellow scientists.

III. Fundamentals Concerning the Tensile Strength of Glass

1. The molecular process of fracture. Breakage occurs whenever the mechanical field of force is strong enough to overcome the electrostatic attraction of the atoms. There are two fundamentally different approaches for calculating the tensile strength; one is restricted to ionic crystals of high symmetry, and the other is of a more general nature and can be applied to both crystalline and amorphous solids.

For simple ionic structures like NaCl, the laws governing the forces between the constituents are well known. Based on these laws it is relatively easy to calculate the stress which results if a given strain is applied to a sodium chloride crystal. Increasing the strain results in an increased stress. If the latter has reached a maximum, the interionic attraction has been overcome and breakage occurs. F. Zwicky[7] carried out these calculations and found that rock salt should have a tensile strength of about 10,000 kg/cm^2. This approach using the "maximum stress" is based on reasonable assumptions, and the calculation involves constants whose values are fairly accurately known. One should expect, therefore, that the results give at least the exact order of magnitude for the mechanical strength of rock salt. Nevertheless, the "technical strength" as measured in the laboratory is only about one thousandth of the calculated value.

The second approach is not restricted to crystals. The material under test is treated as a continuum whose surface is increased when breakage occurs. M. Polanyi[8] discussed the rupture of sodium chloride on this basis. His treatment is also applicable to glasses.

If a glass rod is subjected to increasing strain, elastic energy is stored in the glass. Following Polanyi's ideas we must assume at the moment of rupture the elastic energy is used to create two new surfaces. Glass at room temperature obeys Hooke's Law to the breaking point, that means stress is proportional to strain, or:

Strain (F) = Stress (D) × Modulus of Elasticity (E)

The energy (W) which is stored in each volume element of the glass rod held under uniform tension is:

$$W = \int_0^D F \cdot dD = \frac{F^2}{2} \cdot E$$

The equation allows us to calculate the energy which is stored in a volume element formed by the two new surfaces and having the thickness of r, where r represents the extent of molecular attraction ($r = 5 \times 10^{-8}$ to 10^{-7} cm.). At the moment of fracture the elastic energy of this volume element should be equal to the surface energy σ of the newly formed surfaces. Based on this, one finds for the tensile strength F_{max} of the glass:

$$F_{max} = \sqrt{\frac{2 E \sigma}{r}}$$

By definition the surface energy σ is the work necessary to increase the surface of a body by unit area in a reversible way. For calculating the order of magnitude of the tensile strength, one can neglect the need of reversibility. Amorphous solids have a surface energy of 10^{-4} to 10^{-3} kg/cm/cm^2. This value and also that of the modulus of elasticity ($E = 10^5$ to 10^{-6} kg/cm^2) does not change much with temperature. Substituting the values for surface energy, modulus of elasticity and the distance of interatomic attraction into the above equation leads to values between 10^4 and 2×10^5 kg/cm^2 for the tensile strength of glass.

It is surprising to see that the two absolutely independent methods lead to the same order of magnitude for the tensile strength of the two solids. Nevertheless, the results are in both cases much too high if compared with the technical strength.

Physicists had to find an explanation for this discrepancy between the theoretical and the technical strength of solid matter. This explanation had to be applicable to both crystalline and vitreous materials. Values for the theoretical strength calculated in different independent ways agree among themselves, but are much higher than the experimental values. The experimental values, on the other hand, are reproducible within 5 to 10 per cent if we are dealing with well defined substances like NaCl, tested under controlled conditions (temperature, environment, rate of loading).

2. Tensile strength, a "structure sensitive" property. The failure of all attempts to calculate the strength from the interatomic forces can mean only one thing. The strength is not a function of the average forces holding the ions of crystals or glasses together, but must be governed by certain weak spots in their structures. Just like the weakest link of a chain, and not the average, determines its strength, so many properties of matter are functions of the loosely bound ions and cannot be related to those which are held in normal positions with average bond strength.

Most properties of glasses can be correlated with their structure on the basis of a statistical treatment. Knowing the average interatomic distances, the average coordination number and the average forces acting between the constituents, one can explain properties, such as density, refractive index and thermal expansion. Other properties, such as electric conductivity, photosensitivity and to a certain extent even the light absorption cannot be treated on the same basis. In an electric field, especially at low temperatures, not the average sodium ion migrates, but chiefly those which are more loosely bound than the rest. The discoloring of glasses and alkali halide crystals when exposed to short-wave radiation is not the result of the average alkali ions being changed into neutral atoms (F-centers) but only of those which are weakly bonded, which are close to imperfection in the crystal. The U.V. absorption of most glasses does not have a sharp edge but a "tail" which is caused by those ions which respond to longer waves than the average ion, because they are not held by the same strong forces as the rest.

Properties of solids which are strongly influenced by those constituents which are located near molecular cracks, flaws or imperfections in the structure have been called "structure sensitive."

The mechanical strength is a structure sensitive property. Its value cannot be deduced from the known idealized structure of a glass or crystal. To understand tensile strength one has to take into consideration the flaws and imperfections which are present.

3. The role of flaws. The importance of flaws for phenomena concerning the rupture of solids has been emphasized by A. A. Griffith.[3] In the course of an investigation concerning the effect of surface scratches on the mechanical fatigue strength of metals, a project carried out at the Royal Aircraft Establishment and published in 1920, Griffith found it desirable to test some of his theories using an isotropic amorphous material. This led to the now classical work on the strength of glass fibers as a function of the diameter and the effect of surface cracks on the strength of glass bulbs.

The type of flaw which Griffith had in mind was comparable with the grooves made by filing a metal. He also considered cracks in the interior of the glass originating from the aggregation and orientation of the glass-forming units.

Today our knowledge of flaws in solid matter has greatly increased. From the work of J. Frenkel, W. Schottky, C. Wagner, A. Smekal, A. Joffee, E. Orowan and others, we know that there exists no "ideal crystal." All crystalline materials have imperfections or flaws. These flaws play a very important role in many processes, such as diffusion and solid phase reactions. They are responsible for the discrepancies encountered between the experimental and the theoretical values for mechanical strength and electric conductivity. They must not be macroscopic or even microscopic. A clear and apparently flawless crystal of rock salt or quartz contains certain imperfections which can play the same role as the "Griffith Flaws"; namely, act as stress raisers.

The flaws need not be visible. Most of them are submicroscopic, but can be "developed" by various methods. E. Rexer[9] devised a method to detect the lattice imperfections in rock salt crystals by exposing them to sodium vapor. The sodium atoms deposit in the flaws and produce color centers. The flaws need not be randomly distributed in a crystal. Most of them form during its growth, which often leads to zonar structures. An interesting example for detecting invisible flaws by irradiating a crystal with X-rays can be found in the work of C. Frondel.[10] When he developed a method for the final frequency adjustment of quartz plate oscillators by bombarding them with electrons or by exposing them to X-rays, he found that a clear piece of rock crystal may assume a zonar structure. Evenly irradiated plates were found to develop alternately light and dark smoky bands, 1 mm. and more in width. The bands are arranged parallel to the external faces of the mother crystal and are similar to the color bands commonly seen in natural smoky crystals. Frondel concludes that the color response is apparently conditioned by a sensitizing factor which was already distributed within the crystal during growth. From our experience with other crystals, there is little doubt that irradiation causes an electron transfer which changes the Si^{4+} into elemental silicon. The energy requirements of this reaction are such that only Si^{4+} ions in positions of higher potential energy; that is, near cracks and lattice imperfections, can undergo this change.

That the discoloring of silica under the influence of radiation is not caused by foreign elements, but must be due to flaws, becomes evident from the observation that quartz crystals which do not discolor strongly will do so after fusion. Silica glass in contrast to the crystal must have many more weak spots where Si^{4+} can undergo the change to elemental silicon.

E. N. Andrade and L. C. Tsien[11] applied Rexer's method to develop surface scratches of glass by exposing the sample to the vapor of metallic sodium.

A. Smekal[12] and his students have greatly contributed to our knoweldge of just how these imperfections affect the properties of crystals and glasses. We will later refer to some of their results in more detail.

For the interpretation of electronic processes in crystals, one must subdivide the flaws into several groups, because various types of imperfections behave differently. For our present purpose it is sufficient to know that flaws exist in crystals and glasses, and that under tension they can produce local stresses which exceed the average stress many times.

Griffith[3] gave experimental proof for this assumption by measuring the bursting pressure of cracked bulbs. For evaluating his experimental work he applied the mathematical treatment of C. E. Inglis,[13] who calculated the stress distribution in a plate due to the presence of cracks and sharp corners. We might add here that photoelastic methods have proved that the conclusions of Griffith and Inglis are substantially correct. For the details one might consult the book of E. G. Coker and L. N. G. Filon,[14] where equations are presented, which give the maximum stress at the apex of an eliptical flaw.

The presence of flaws, imperfections and scratches at the surface accounts for the fact that glasses and crystals are much weaker than we would expect from a reasonable estimate of the interatomic forces. The flaw theory, in addition, provides an explanation for the phenomenon that higher values are found for the tensile strength if the volume of glass under tension is decreased. It is obvious that with increasing volume or increasing surface, the probability of meeting a dangerous, more effective flaw increases. With this information, however, we cannot derive from the flaw theory the reasons why glasses should behave differently from metals and certain plastics. In order to shed more light on the peculiarity of glasses, we have to investigate how different materials react to the flaws when brought under tension. Studies of the influence of temperature, rate of loading and of the environment of the test piece have been found very revealing.

4. The influence of temperature on the tensile strength. Theoretical reasons and experimental evidence point out that the strength of matter decreases with increasing temperature. Thermal motion helps to sever the bonds between the atoms under tension. It was not surprising, therefore, when evidence was presented by several workers that the tensile strength of glass is higher when tested at lower temperature. Among the first workers in this field, J. V. Kowalski,[15] H. Kammerlingh Onnes and C. Brook,[16] as well as O. Graf,[17] should be mentioned. Recent experiments over a wide temperature range confirmed those early observations, but also established the fact that the strength increases with increasing temperature. In other words, glass at room temperature has a minimum mechanical strength. Lowering the temperature to that of liquid air or raising it to 500°C. increases the tensile strength.

A. Smekal and his students, especially K. Mengelkoch,[18] made systematic experiments on the influence of temperature on the tensile strength of glass. Their results have been corroborated by several independent workers. J. S. Gregorius,[19] for example, tested glass laths by bending them until fracture occurred. At 540°C. his glass was 40% stronger than at room temperature. The minimum strength was found at 300°C.

Results of a very careful determination of the strength of glass as a function of temperature were reported by F. W. Preston.[6] In this work, carried out by B. Vonnegut in the Preston Laboratories, special precautions were taken to keep other factors constant. Again we find a distinct minimum around 200°C.

G. O. Jones and W. E. S. Turner[20] exposed fire polished specimens of glass laths to a load which was 70% of the rapid breaking load and determined the time for which the samples could endure this load at different temperatures. This endurance test confirmed the results of previous workers that glass becomes stronger with increasing temperature. The upper limit for determining the tensile strength is given by the deformation of the glass. For silica glasses an increase has been found up to 800°C. as can be seen from the data obtained by W. Dawihl and W. Rix[21]:

20°C.	10.0 kg/mm²
150°C.	12.2 "
800°C.	13.4 "

Smekal attributes this increase in strength with increasing temperature to the rounding of the sharp edges which makes the flaws less dangerous.

The calculations of C. E. Inglis, [13] to which we referred previously, indicate that the maximum tension increases very rapidly if the radius of curvature at the stress raising apex of a flaw becomes smaller. Sharp notches, where the radius of curvature reaches the low values of molecular dimensions, are, therefore, the most dangerous. The rigidity of glass at room temperature and the absence of gliding planes prevent atomic rearrangement which might "heal" the crack. Only at higher temperatures, where the breakage of major bonds becomes probable, can the migration of atoms along the surface of the crack help to smoothen the sharp grooves and to increase the radius of curvature of the stress-raising centers.

Considering the paramount influence which the flaws have on the strength of glass, one can easily understand the reason why, with increasing temperature, the healing of cracks outweighs the influence of thermal motion which by itself would help to sever the connection between the atoms already under tension. The antagonistic effects produced by increasing temperature, namely, severing the bonds between the constituents and paralyzing the effect of dangerous flaws by surface diffusion, produces the minimum in the temperature strength curve. The failure of glass above the softening range where the glass loses its rigidity is due to deformation or flow, and is analogous to the creep of metals.

In Fig. 1 the strength as a function of temperature is schematically represented as the resultant of three

(*Continued on page* 32)

GLASS CONTAINER MANUFACTURERS INSTITUTE MEETS IN MIAMI

The first Semi-Annual Meeting of the Glass Container Manufacturers Institute was held at the Sea Isle Hotel in Miami Beach during the first week in December. On December 3rd and 4th, regular members, trustees and representatives of contributing companies received the first semi-annual reports of the various Standing Committees of the Institute in conformity with its Code of Regulations.

On Wednesday, December 5, a meeting of the Membership comprising glass container and closure manufacturers and members of allied and supply industries was called to order by George F. Lang, the Institute's president. At this meeting, in addition to the report from the president, other reports were delivered by Fred E. Fuller, General Counsel, a membership report by Victor L. Hall, General Manager of GCMI and one by its Secretary-Treasurer, Harry W. Kuni, on finances.

Following the reports, the budget for 1946 was presented; also a proposal to amend the Code of Regulations relating to membership of foreign corporations.

Determination of a place of meeting for the Annual Meeting scheduled for May 9, 1946, was discussed but no conclusion on this matter was reached. Immediately following this final session, a luncheon and meeting of the Board of Trustees was held.

The business program of the meeting was exceptionally well planned and under the direction of its presiding officer, Mr. Lang, punctuality and smoothness were the order of the day. All matters on the agenda were handled in three half-day sessions. On Monday, December 3, the first of the reports of the Chairmen of the Standing Committees was presented. The first of the reports came from Louis C. Roche, of the Maryland Glass Corporation and Chairman of the Committee on Labor Relations.

Labor Relations

Mr. Roche's report covered the activities of his Committee from June to November 1945 and, after presenting for the record the names of the ten Labor Committee members representing as many individual glass container companies, he outlined in considerable detail the work of the Labor Committee and the results of its deliberations at its meetings in Cleveland on June 26, 1945 and in Atlantic City on July 9 and September 19 and 20.

There are so many ramifications to the Labor Committee's problems that an attempt to even briefly outline within the limitations of this report would not be practicable.

Of considerable interest in Mr. Roche's report, however, was the appointment of Ralph A. Lind as Secretary and Labor Counsel to the Institute's Committee on Labor Relations. Mr. Lind's appointment was for the period of July 1 to December 31, 1945, on a part time basis. After Mr. Roche finished his report, the matter of retaining Mr. Lind's services received considerable attention. Some strong opposition to the idea was offered on the premise that a part time Counsel could not do justice to the problems of the glass container industry, but Mr. Roche maintained that disregarding all other considerations "half a loaf was better than nothing," and, since it would be most difficult to find a suitable full time secretary-counsel within the limited time available before the expiration of the arrangement with Mr. Lind, this arrangement should be renewed for at least another six months. This proposal was finally acted upon favorably.

Government and Industry Relations

The next Standing Committe report was that of the Chairman of the Committee on Government-Industry Relations, C. Dudley King of the Anchor Hocking Glass Corporation. This Committee is comprised of individuals from four glass container companies, one closure manufacturer and one manufacturer of cap liners.

Mr. King in his report to the Membership outlined the work of the Committe with emphasis on the fact that during the six months period to the time of his report the Committee has issued eleven bulletins covering some twenty-eight subjects of concern to glass container and closure manufacturers or their customers. It was also pointed out that the Committee had maintained important contacts with the many war agencies, such as the War Production Board, War Food Administration, War Manpower Commission and the Department of Commerce. This work was of great service to these government agencies both from the glass container industry's standpoint and the general public.

Mr. King also discussed the remaining government controls in effect at the time of the meeting. In this connection, he stated his opinion that the retention of Order L-103 would be of great benefit to the packer and consumer until supply and demand of glass containers can be brought into better balance.

Container Design and Specifications

S. B. DeMerell, Anchor Hocking Glass Corporation, as Chairman presented the report of the Committee on Container Design and Specifications. This Committee is composed of 1) Committee-at-Large, 2) Sub-Committee on Beer Bottles and 3) Sub-Committee on Milk Bottles.

Mr. DeMerell stated that "following the organizataion of this committee, it was found desirable to have a subcommittee of technical production men for the purpose of reviewing the recommended standards and the make-up of the final drawing, etc., prior to their issuance to the industry."

This Technical Sub-Committe is composed of four members from four different glass container companies. Meetings of the main committee and technical committee have also been attended by Ball Bros. Company, Hazel-Atlas Company and Owens-Illinois Glass Company, all participating companies.

Other matters discussed in some detail by Mr. DeMerell pertained to capacity, weight body tolerances and the effect of the use of standard containers on the industry's ability to produce.

In this connection, Mr. DeMerell cited figures of production of glass containers published in THE GLASS IN-

DUSTRY to illustrate the effect of the use of standards for increasing production.

Notwithstanding the estimated production of one hundred and five million gross of glass containers in 1945, it is believed that the present demand exceeds supply by at least twenty per cent. This would indicate, it was pointed out, that demand is running at about the original WPB estimate of one hundred and twenty million gross for 1945.

In furtherance of his argument for continued adherence to standards, Mr. DeMerell stated, "New users find it virtually impossible to place orders and in many instances where orders are accepted, I understand delivery promises run well into the summer of 1946. In the light of the above backlogs, plus surveys made by several individual manufacturers, it seems reasonable to believe that the present peak demand will continue at least through 1946.

"This brings us to the position our trade would be in if the demand returns to the pre-war pattern, including small sizes, odd capacities and private molds. Detailed studies have been made by individual members of the Committee measuring the efficiency of an entire plant as it operated in 1940. The conclusion reached by these independent investigations indicates that a return to the 1940 pattern would reduce production by at least 20 per cent. This would mean that in place of increasing the output next year to a possible 110,000,000 gross (as many feel is attainable), the industry would turn out in the neighborhood of 85-90,000,000 gross. Actually, the above figures in gross tell only part of the story. While the number of containers produced since 1940 has increased over 90 per cent, the packaging capacity (gallonage which these containers would hold) has increased more than 150 per cent, the difference in the two figures being due to the elimination of many small capacity sizes. With a return to the smaller capacities in addition to special designs, it is estimated that the packaging capacity would be reduced by approximately 40 per cent.

"So long as the present demand continues, it would seem that the industry's trade has no logical alternative than to continue the use of standard containers. Action which would have the effect of reducing the industry's maximum production in gross and packaging capacity would seem to be of the nature of a calamity so far as the bottlers and packers are concerned."

Package Design and Specifications

The Committee on Package Design and Specifications, which is concerned with safe, economical and efficient packaging of glass containers and glass packed products, is headed by C. A. Reese of Tygart Valley Glass Company. Mr. Reese was unable to attend the Miami Meeting. Therefore, his report was presented to the membership by B. H. Taylor, the Institute's Traffic Director.

In a foreword to his report, Mr. Reese stated, "Among these activities are the promotion of and participation in laboratory investigations of the strength of packaging materials, development of carton and interior packing specifications for use in brochures or in an industry packaging manual, and cooperation with the Institute's Traffic Committee in problems relating to carriers' packaging requirements. The Committee believes the scope of its activities, with such assistance as it is permitted to obtain from non-member company consultants as set forth in the Institute's Code of Regulations, is sufficiently broad to enable it to do the job it was created for."

Thus far, the major problem which confronts this Committee is that which concerns fibre cartons and interior packing specifications as they relate to glass containers and glass products and which are now published in tariff form.

It was stated that the railroads do not consider the present specifications as carried in Consolidated Classification Rule #41 adequate packing of glass containers and glass packed products and that they undoubtedly intend to revise this rule as soon as the fibre board and paper board situation is eased. It is also felt that motor carriers and the Express Agency will follow this lead.

In concluding his report on this important traffic matter of interest to users of glass containers, as well as glass companies, Mr. Reese stated, "There seems to be only one of two courses the glass container industry can take in dealing with this matter. One would be to let the railroad classification committee promulgate their own revised specifications. It is conceivable that if this were done the specifications would be arrived at strictly from the carrier's viewpoint as to what they ought to be, which, in the light of information at hand, might prove to be very costly to the industry. The other would be for the industry to work with the railroad classification committees in formulating the specifications. The railroads will welcome such collaboration from the industry provided the latter can support its views as to what constitutes adequate packaging specifications. This involves a good deal of exploration and properly organized testing methods and procedures.

"The committee believes it would be to the best interest of the industry and the public to work with the carriers in determining the specifications that should be incorporated in the consolidated freight classification. With this in view, it has taken the first steps towards a program to be followed. That program will require approval of the industry and will be explained at the industry meeting to be held in December. Since the program has not yet been made known to the industry, the committee believes it would be best to await action of the industry at its December meeting before making a full report on the subject."

Testing Procedures

The first report of the second day's session was made by K. C. Lyon of Armstrong Cork Company and Chairman of the Committee on Testing Procedures.

Because the scope of this Committee is rather broad and Dr. Lyon's report was a comprehensive one, this report cannot really do full justice to the work being done by this Committee. An outline of its activities from June to November 1945 may give the reader some idea of the importance of this work.

Six glass container companies are represented on the Committee and among the six individuals representing these companies, the following were selected as officers: K. C. Lyon, Chairman, W. R. Lester, Maryland Glass Corporation, Vice Chairman and L. G. Gehring, Preston Laboratories, Secretary.

Dr. Lyon stated that during the period covered by his

(*Continued on page* 40)

THE WELDING OF GLASS TO METAL

By E. M. S. WOOD*

The fusing of glass around metal wires to make sealed joints has been practised ever since ordinary electric lamps became a commercial product: but it is only in the last few years that the application of fused metal to glass as a surface treatment has been successfully developed. Although the intimacy and strength of the marriage between the metal and the glass are remarkable, it is perhaps going rather too far to call the process "welding". The term can almost be justified in respect of the subsequent operation of soldering metal objects on to metal-coated glass which can be performed if desired. This account is a brief review of the work of research and development that has been done on these interesting processes by British enterprise.

The process consists in using the "Schoop" Metal-spraying Pistol or Gun to spray finely divided fused metal on to the glass, which must be preheated to obtain adhesion. The only metals with which the process is readily effective are aluminum or alloys of aluminum with small amounts of manganese; and with these metals adhesion is secured if the glass is at a temperature of about 300° C when sprayed. Subsequently other metals such as copper can be sprayed on to the aluminum if it is necessary to provide a metal surface which will take solder. Workers in the United States, using rather higher preheat temperatures for that part of the glass which is to be sprayed, have succeeded in applying copper containing small amounts of alloying metals directly to the glass.

A very successful application of the process originated by the St. Gobain company in France is the making of electric heaters in the form of glass plates, the surfaces of which carry a resistor element in the form of a long strip of aluminum: the current passing through this strip heats the strip and the glass. Much work on developing the manufacture and testing of such heaters has been done in Britain. A heater consists of two such plates mounted face-to-face so that the live metal is not exposed to accidental external contact, and a temperature up to about 140° C is conveniently obtained. The glass plates must be toughened, this being necessary for withstanding the thermal conditions both of the spraying process and of service as a heater.

Using the "Schoop" Gun

Each plate, thoroughly cleaned after toughening, is heated to 300° C in a furnace and then placed nearly upright with a steel template or stencil over it defining the pattern of the strip to be sprayed on. The "Schoop" Gun is then used to spray the aluminum on to the glass through the template, it being necessary to complete the application of an initial coat before the temperature of the glass has fallen sensibly below 300° C. Afterwards more aluminum may be sprayed on when the plate is cold, as may be needed to adjust the thickness of the aluminum to bring the electrical resistance of the strip

Fig. 1

to the required value. To avoid excessive thermal strains in the glass when the heater is in use the strip must be applied in a pattern which covers the plate uniformly and near to the edges, the usual design being straight parallel strips from ¼ to ⅜ inches wide with spaces of 3/16 to ¼ inches between them. Ornamental patterns can be used if they give uniform heating effect. The geometrical shape of the plates must be fair and regular without re-entrant corners and there should be no drilled holes in the glass.

The "Schoop" Gun uses the metal in the form of wire which it melts with an oxy-gas flame and atomizes and projects at high velocity by means of a compressed air stream. The resulting coating of metal formed on the glass is granular in nature, composed of discrete solidified droplets each of which has acquired a thin coat of oxide. As a result the sprayed strip on the glass has a much higher electrical resistance than solid aluminum of the same cross-section: moreover its resistance will need accurate adjustment, as shown by electrical test, and this is done by "touching-up" thin places by spraying on more metal.

Each plate is completed by spraying a patch of copper on to the aluminum at each end of the strip, and then soldering a suitable terminal on to the copper.

Thin Coat of Copper

The fact that a surface capable of taking solder can in this way be applied to glass provides the second use-

(*Continued on page* 46)

*Mechanical scientist on the technical staff of Pilkington Brothers, Lancashire, England.

INVENTIONS AND INVENTORS

A Summary of Recently Issued Patents of Interest to the Glass Industry

Feeding and Forming

Edward Danner is the inventor of patent No. 2,390,925 on a Tube Forming Machine in which the tube descends from a submerged orifice. Fig. 1 is a vertical section through the tube forming apparatus. Here is shown a portion of a forebay 32 containing a pot 56 which receives the glass from a forehearth connected with a tank. An outlet 51 extends downwardly, and passing therethrough is a refractory tube 48 inclosing a blowpipe 47.

Surrounding the outlet 51 is a cylindrical shell 50, the upper surface of which is slightly below the glass level. This shell may be adjusted vertically at several points on its circumference by the wedge-like action of the movable blocks 54 and the cooperating angular surface 55 formed on the shell 50. The lower end of the blowpipe carries a block 57 having an annular shoulder 58. This forms an annulus between the shoulder 58 and a shaping element 60 through which the glass flows to the interior and also the exterior of the shaping element 60. The temperature of the glass on the shaping element is controlled by burners 65 which are spaced below a heat-confining shell 64. The heat may be localized and further controlled by an adjustable shield 66 supported by a frame 67. This shield may be adjusted vertically by a crank actuating a pinion 72 which engages a rack 70 connected to the frame 67.

Several modifications of this invention are also described in the patent.

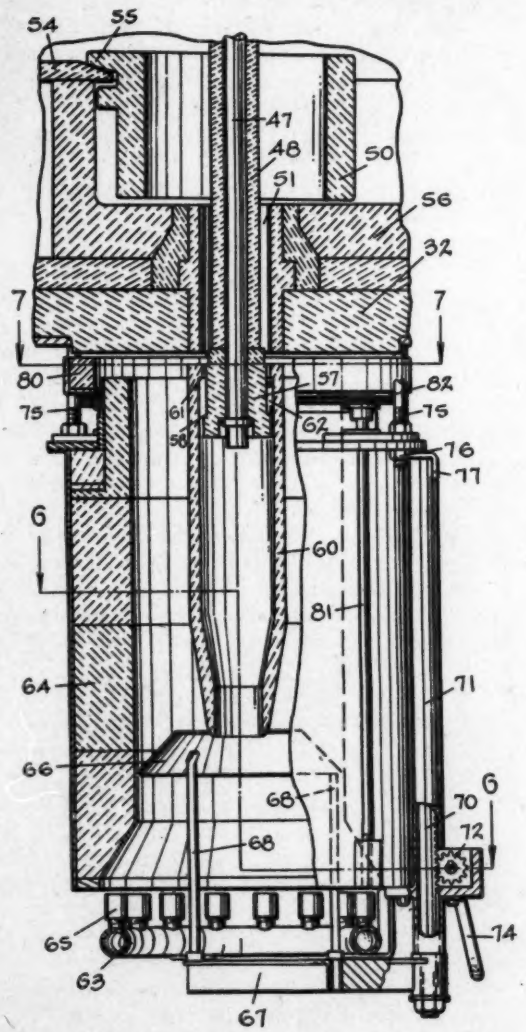


Fig. 1. Patent No. 2,390,925, Danner Tube Forming Apparatus.

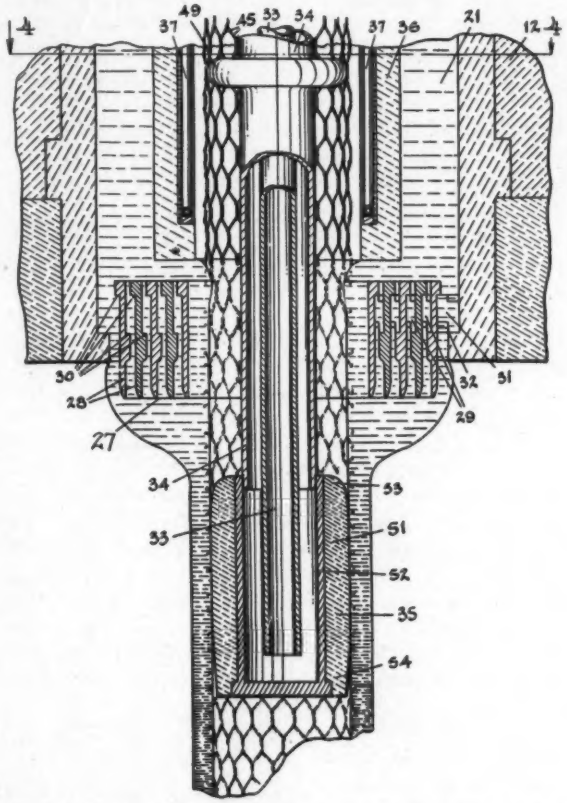


Fig. 2. Patent No. 2,390,926, Apparatus for making Reinforced Glass Tubing.

Patent No. 2,390,926, issued to Edward Danner, appears to be a development from his patent No. 2,390,925 noted above. The most outstanding characteristic of the later patent is that the mechanism is arranged to form a glass tube which may be cylindrical or of other shapes extruded downward from an outlet and having incorporated therein a reinforcement of wire netting similar to the usual wired flat glass.

Fig. 2 shows the most important departures of construction from his earlier patent. The glass flows downwardly from a forehearth through the outlet 21 having at its lower end a glass shaping element 27 comprising

a plurality of concentric shells 28 spaced from each other by blocks 29. The glass flows down inside of these shells, between them, and outside of them, and forms a tube having a relatively thick wall. Water cooled pipes 33 and 34 depend to a point well below the element 27. The outer pipe 34 carries at its lower end a shaping member 35 which is preferably made of graphite. This shapes the inner surface of the tube being formed.

The netted wire 45 may be introduced in the form of a cylinder having its edges fastened together if desired. The wire is centralized and guided by the flange 49 and it is fed downwardly so that after passing the graphite shaping member 35 the reinforcing wire is embeded in the tube. Suitable mechanism is provided for drawing the tube thus formed downwardly and for feeding the reinforcing wire at the proper rate.

A glass feeder, invented by James W. Ross, shown in patent No. 2,390,176, has been assigned to Hazel-Atlas Glass Company. This patent shows a pneumatic feeder in which pressure and vacuum are alternately applied to the surface of the glass over an outlet to control the extrusion and retraction of the glass at the outlet. The principal novelty of this invention is that the application of positive and negative pressures to the glass is controlled by the movement of the shears.

As shown in Fig. 3, air is admitted to the front and back of a cylinder 11 through pipes 12 and 13. This cylinder contains a piston mounted on a piston rod 14 carrying a yoke 25' which actuates the opening and closing of the shears 10.

The piston rod 14 projects rearwardly from the cylinder 11 into a cylinder 15. A piston in the cylinder 15 is actuated simultaneously with the opening and closing of the shears, thus providing an alternate pressure and vacuum in the rear of the cylinder 15. In order to vary the duration of the vacuum, a pipe 26 is provided with a check valve and a throttle valve which permits regulation of the vacuum built up in the rear of the cylinder.

The pressures built up in the cylinder 15 are transmitted through a pipe 18 to a valve block 19 and thence by a pipe 9 to the interior of the tube 4. The valve block 19 contains a valve which is opened and closed by connections including the parts 20, 23 and 24'. A lug 24 fixed on the shear yoke 25, opens and closes the valve with the opening and closing movement of the shears. An adjustable lost motion is provided by the nuts 24' so that the time of admitting pressure and vacuum to the tube can be adjusted. The pipe 9 is bifurcated and provided with check valves and throttle valves in each side so that the volume of pressure and vacuum can be independently controlled.

A mercury tube 33 is preferably connected to the pipe 9 and calibrated to indicate the level of glass in the feeder tube 4.

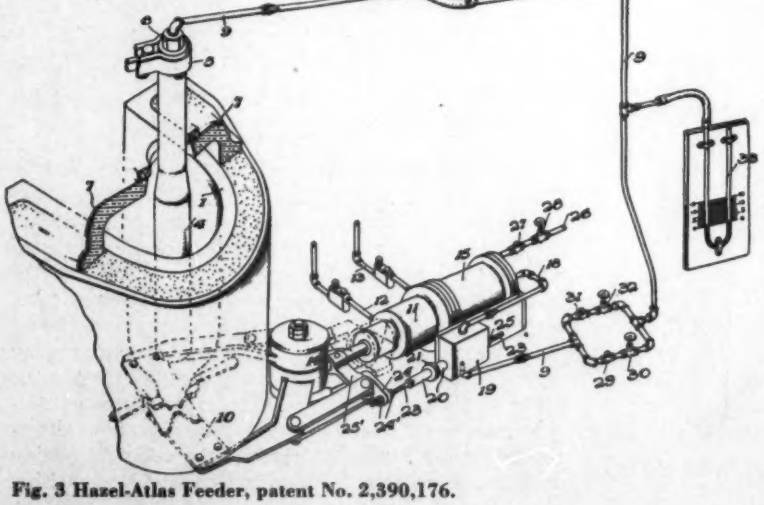


Fig. 3 Hazel-Atlas Feeder, patent No. 2,390,176.

Glass Composition

John E. Stanworth of Sheffield, England, has assigned patent No. 2,390,191 to General Electric Company. This composition provides a new range of glasses having such powers of expansion that they may be used for joining two parts made from glass of other composition, or for sealing to many ceramic materials or iron alloys. The necessary softness of this composition is obtained by using a high percentage of phosphorous pentoxide and boric oxide, and 8 to 16 per cent of alumina is added to increase durability.

The following is one example of glasses coming within this range, the percentages being given by weight.

P_2O_5	28 to 38%
Al_2O_3	8 16
B_2O_3	13 22
$ZnO + MgO + BaO$	24 34
Na_2O	6 10

With the molecular ratio of P_2O_5 to Al_2O_3 being within the range of 1.5 to 3.0.

Raymond W. Goodwin is the inventor of patent No. 2,389,305 which is assigned to the General Electric Company. The invention relates to a glass used in sealing metal to iron in all of its various forms. This material is used particularly for sealing the lead-in connections for electronic discharge devices, electric lamps, etc. It is an improvement on another glass composition, patent No. 2,272,747, invented by A. W. Hull et al and assigned to the same company. This glass differs from others heretofore suggested for this purpose in the use of aluminum oxide in amounts of 1 to 8 per cent; the use of lithium oxide and the elimination of flourspar.

Example of one recommended composition of this glass is as follows:

SiO_2	40 to 48 per cent with 45 per cent average in preferred examples
Al_2O_3	1 to 8 per cent
Li_2O	1 to 2.5 per cent
Na_2O	2 to 5 per cent with the sum of $Li_2O + Na_2O$ averaging about 4 per cent
K_2O	12 to 17 per cent
Total Alkali Oxides..	Not over 19 per cent
PbO	32 to 38 per cent

Carl J. Harbert and William C. Morris have assigned their patent

on Glass Enamel Composition, No. 2,390,366, to the Harshaw Chemical Company. This composition provides an enamel fusing at a comparatively low temperature and suitable for application to glass. The previous patents have taught that the use of titania and zirconia in enamels of this type will secure increased acid and alkali resistance. A prior United States patent, No. 2,338,099, teaches the use of zirconium dioxide and alkali metal fluorides for the purpose of lowering the melting point and improving the brilliance of the glass when pigmented with cadmium colors.

These inventors have discovered that zirconium tetrafluoride and zirconyl fluorides can be substituted for zirconium oxide and alkali fluorides, thereby increasing the alkali resistance while the acid resistance of the enamel is not reduced.

The following are two examples of the above smelter batch compositions which come within the scope of this patent.

Sample number	1	2
Smelter Batch (Parts by Weight)		
Sodium silicate	16.30	16.10
Lead monosilicate	52.50	50.50
Zinc oxide	0.80	0.80
Cadmium hydrate	2.60	2.50
Silica	10.60	11.00
Barium carbonate	3.30	3.30
Boric Acid	7.50	7.60
Titania	1.70	1.70
Zirconium tetrafluoride	4.70	——
Ammonium fluorzirconate	——	6.50

British patent No. 570,111 is a glass composition invented by employees of the Corning Glass Works. It discloses a method of making colored glass from a composition containing copper. An example of this composition and method sets forth a glass batch containing copper equivalent at least to .05% Cu_2O and a reducing agent, and preferably a small amount of tin oxide. This batch is melted and formed in the usual way. The article is then irradiated as by means of a mercury arc. The article which was originally colorless, after irradiation for ten seconds or more becomes light blue, and if subsequently heat-treated becomes red. It is suggested that a portion of the article may be shielded from irradiation, thereby producing different colors in the same article.

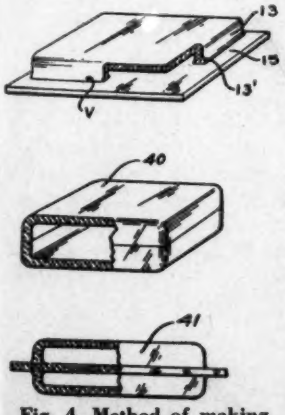


Fig. 4. Method of making Double Glazed Windows, patent No. 2,389,360.

Miscellaneous

Patent No. 2,389,360 is on a method of making double glazed panes, particularly for use in windows. This patent was assigned to Corning Glass Works by Guyer, Littleton and Shaw. Fig. 4 shows three forms of this invention, all of which may be made by the same method.

A flat sheet of glass is preferably placed over a rectangular form so that the marginal edges of the glass project beyond the form, and these edges are then heated so that they drop on all four sides to form a shell or shallow walled container. One way to heat the marginal edges is to apply a coating of conducting material along the edge and then pass a high frequency current through this coating. Before the conducting coating is destroyed, the glass becomes heated and is a conductor itself. Colloidal graphite applied by a brush or by spraying has been found to be a satisfactory conductive coating. After the edges have dropped, the shell is placed in contact with a sheet of glass 15 and the shell is sealed onto this sheet by further heating in the same manner as was used to form the shell originally, except that the current then passes through a conductive coating applied to the bottom of the sheet 15 opposite to where the seal is to be made.

A vent V is provided to prevent collapse of the double pane, due to subatmospheric pressure caused cooling. After the article has been annealed, any moisture in the article may be removed by various means such as blowing dry air in through the vent V, after which the vent is sealed.

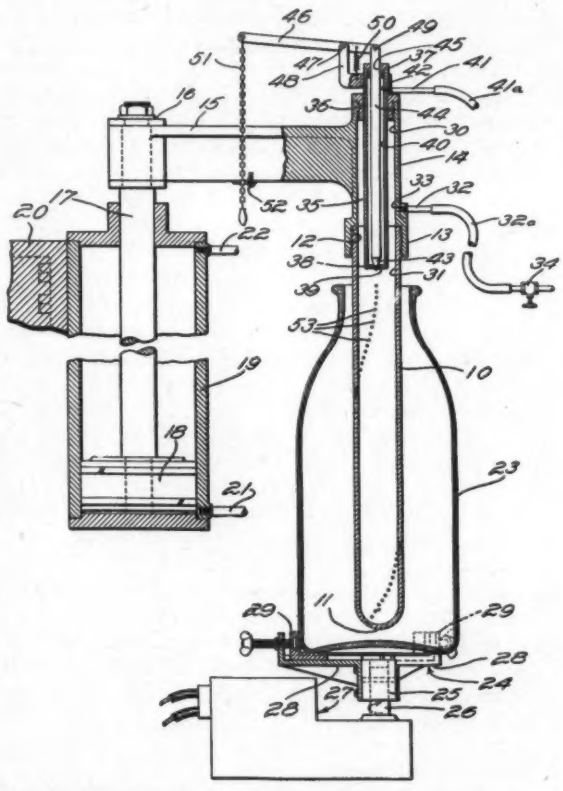


Fig. 5. Patent No. 2,390,910, Method of Tempering Glass Bottles.

Another form of the invention is shown at 40. This is made by the same general method as the one previously described except that instead of sealing the shell onto a flat sheet, it is sealed to a second similar shell.

In the third form shown at 41, two shells are sealed to the opposite sides of a flat sheet.

(*Continued on page 44*)

GJ Research Digest

Practical Interpretations of Glass Technology

Abrasion of Glass as Related to Composition

In the commercial grinding and polishing of glass for various purposes, the interesting property is not the surface, but the degree of abradability, or inversely, the resistance to abrasion. Scholes (*Journal of the American Ceramic Society*, May, 1945) reports on a study of this property. The abradability of glass of different compositions was estimated by grinding on a steel plate with powdered quartz as an abrasive, determining the weight removed from the ends of glass rods, reducing this to volume, and comparing the volume removed from used silica rods by the same treatment.

From the results obtained, a few general conclusions were drawn. Silica is, by all odds, the most important component in resisting abrasion. Lime seems to have little effect when it is substituted directly for soda in a sodium silicate. Since the sodium borate is the softest of all the glasses investigated, it is evident that boron oxide is much less effective than silica in supplying hardness. However, when boron oxide replaces lime, the glass becomes less abradable. The relative hardness of the commercial compositions may possibly be explained by their complexity rather than by attributing any particular degree of hardness to the separate components. A small addition of alumina appears to have scarcely more effect than the same addition of lime as replacing soda.

The data obtained was too fragmentary to warrant the derivation of factors or other numerical expressions designating the effect on abradability to be expected from each component oxide. It is interesting to note—and this is entirely in accordance with published observations on scratch hardness—that commercial glasses show, on the whole, no great range of abradability but that all of them are approximately three times as abradable as pure silica. The low coefficient of Pyrex-brand glass may reasonably be attributed to its high-silica and low-alkali contents.

Glass-to-Metal Seals

In the April, 1945, issue of the *Journal of the Society of Glass Technology*, Redston and Stanworth present a comprehensive study of the properties of glass to metal seals. A brief summary of their paper follows.

Photoelastic measurements have been made on standard sandwich seals over a wide temperature range by means of the stress optical bench. Between room temperature and the annealing range for a seal, the stress varied considerably and usually changed its sign. The stress at any temperature could be altered considerably by a change in the thermal treatment of the seal. Change of stress with temperature depended mainly on differential free contraction between glass and metal, but in the annealing range of the glass, the stress was modified by viscous flow. Where the metal had a low yield point (e.g., copper), the stress in the glass was much lower than that anticipated from differential free contraction.

Axial stresses were determined for bead seals at room temperature using the method of A. W. Hull and E. E. Burger; and the theoretical relationship between P_z and the ratio of the radii of the glass and metal components was verified by measurement. Hence, the determination of axial stresses in seals could be used for rapid routine checks on the thermal expansion properties of glasses. It was also concluded that the permissible value of the stresses in bead seals at room temperature depends upon their actual design and application, and in some cases can safely be considerably in excess of 1 kg/mm.^{2} tension.

Annealing Strains in Glass and Their Degree of Permanence

Ghering and Green (*Journal of the American Ceramic Society*, October, 1945) have made a statistical comparison of 13 sets of measurements of optical path difference taken over a seven-year period on 24 samples of the standardized disks which were distributed in 1938 to the manufacturers of glass containers. The data obtained showed that the original optical retardation of about 22.8 millimicrons has not changed by more than ± 1.3 per cent, equivalent to ± 0.30 millimicron or $\pm 0.10°$ on the scale of the measuring instrument.

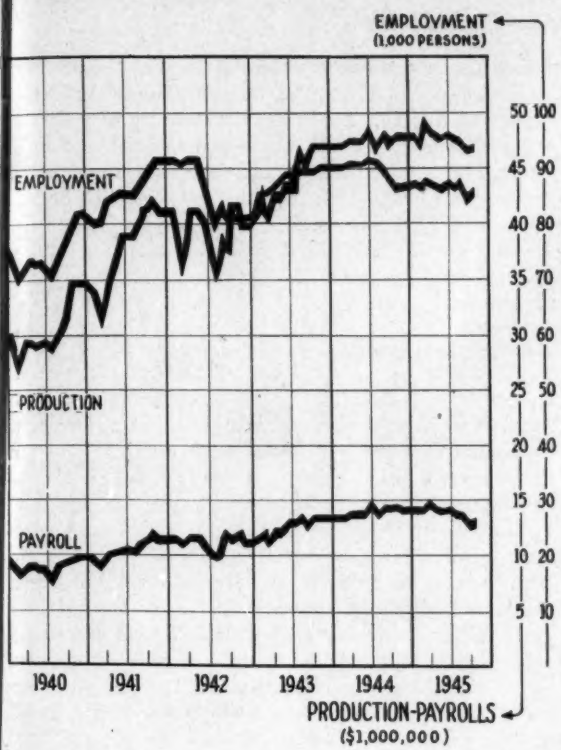
Five tests were made in 1938, five in 1945 and three between. The standard deviation of the combined errors for each of the 13 averages of 24 measurements is $\pm 0.0338°$ and is composed of an accidental error of observation of $\pm 0.0005°$ and an error of adjustment of the instrument of $\pm 0.0333°$. The range of ± 1.3 per cent, or $\pm 0.10°$, beyond which the disks could not have changed over seven years, represents the 3-sigma probability limit of combined errors.

It was concluded that the possible change of $\pm 0.10°$, equivalent to ± 0.30 millimicron, and within the experimental error of measurement, is too small to have the slightest effect on the utility of the standards in use by glass manufacturers. This experimental error and possible change in stress is too great, however, for drawing broad conclusions concerning the stability of glass at room temperatures with respect to annealing stress.

• It has recently been reported that the government will have to use 25,000 tons from the government lead stockpile during the first three months of 1946. It is being urged that glass manufacturers watch their lead chemicals supply carefully.

CURRENT STATISTICAL POSITION OF GLASS

THE GLASS INDUSTRY'S INDEX



Activity in the glass industry during October, 1945, indicated an approximate 3 per cent increase over September reports by the $44,900,000 shown by the Production Index. September production was reported to be $43,600,000. October, 1944, was shown to be $48,000,000, which is about 6 per cent higher than for October, 1945. Output for the first ten months of 1945 totals $465,800,000 as compared with $476,000,000 for the same period in 1944.

Employment and payrolls: The total number of persons employed in the glass industry throughout October, 1945, were 86,600 persons. For the month of September reports showed that 84,500 persons were employed and 87,100 in October, 1944.

Payrolls for October, 1945, were $12,205,000. This is an approximate increase of 3 per cent above the $11,850,000 reported for September. The figure also represents an approximate 17 per cent decrease from the $14,750,000 reported for October, 1944. During the first ten months of 1945, $132,055,000 has been paid in salaries by glass manufacturers, as compared with the $141,750,000 paid out during the same period in 1944.

THE GLASS INDUSTRY has been advised by the Bureau of Census that due to a slight change in the method of compiling the following figures on production and shipments of glass containers starting with the month of November, comparisons with the preceding month and the same month a year ago could not be absolutely accurate. Also, one additional company is now reporting. The new system adopted will provide uniform reporting for all concerns insuring greater accuracy in classifications of types of ware produced and shipments made.

Glass container production for November 1945 was reported at 8,902,491 gross—an approximate 9 per cent decrease from the 9,847,011 gross reported for the previous month. November 1944 production was 7,967,358 gross, or about 11 per cent less than for November 1945. Total production for the January-November 1945 period is 96,763,946 gross—an approximate 3 per cent over the same period in 1944.

Shipments of glass containers during November 1945 totalled 8,868,635 gross, a decrease of about 9 per cent from shipments in October. November 1944 shipments were about 13 per cent under November 1945 and were

GLASS CONTAINER PRODUCTION AND INVENTORY

(All figures in gross)

		Production Nov., 1945	*Stocks Nov.*, 1945
Foods; Medical & Health Supplies; Chemicals, Household, Industrials; Toiletries & Cosmetics	Narrow Neck	2,783,761	1,647,524
	Wide Mouth	3,227,737	1,017,552
Dairy Products		310,729	166,703
Home Canning		98,782	287,043
Beverages, Returnable		516,594	315,208
Beverages, Non-returnable			
Beer, Returnable		397,262	88,744
Beer, Non-returnable		264,083	38,863
Liquors		978,642	207,237
Wines		229,764	78,645
Packers' Tumblers		75,127	6,823
Total		8,902,491	3,854,342

GLASS CONTAINER SHIPMENTS

(All figures in gross)

Narrow Neck Containers	*Nov.*, 1945
Foods	592,409
Medical & Health Supplies	1,067,656
Chemical, Household, Industrials	594,530
Beverages, Returnable	506,658
Beverages, Non-returnable	
Beer, Returnable	371,152
Beer, Non-returnable	252,533
Liquors	913,471
Wines	213,688
Toiletries & Cosmetics	542,483
Sub-Total (Narrow)	5,054,580
Wide Mouth Containers	
Foods	2,629,691
Dairy Products	311,814
Home Canning	52,556
Medical & Health Supplies	272,207
Chemical, Household, Industrials	147,817
Toiletries & Cosmetics	123,828
Packers' Tumblers	77,147
Sub-Total (Wide Mouth)	3,615,060
Total Domestic	8,669,640
Export Shipments	198,995
Total Shipments	8,868,635

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reported to be 7,787,433 gross. The first eleven month of 1945 show total shipments to be 98,546,613 gross compared with 89,063,561 for the same period in 19 —a difference of approximately 10 per cent.

Inventories on glass containers for November 19 were 3,854,342 gross, indicating a slight rise above O tober inventories, and an approximate 27 per cent dro from November 1944.

Plate glass production for the month of Novembe 1945, dropped to 543,146 sq. ft., according to the Hughe Statistical Bureau. Strikes in the industry considerabl curtailed activity for the month and caused the drop i plate glass production. October figures showed a pro duction of 7,334,978 sq. ft. and November, 1944, a pro duction of 7,618,959 sq. ft. This makes a total of 84 159,103 sq. ft. production for the first eleven months o 1945 as compared with 94,924,718 sq. ft. produced dur ing the corresponding period in 1944.

Automatic tumbler production for the month of No vember 1945 is reported to be 5,721,966 dozens a compared with 6,221,055 dozens produced in Octobe 1945. The November figure represents an approximat 8 per cent decrease from October. November 1944 pro duction was 4,361,151 dozens which is about 31 per cen less than for November 1945. Shipments for November 1945 were 4,945,220 dozens, while for October they were 6,025,802 dozens—a difference of about 17 per cent. November 1944 shipments were 4,232,116 dozens or about 16 per cent less than for November 1945. In ventories for November 1945 were 5,259,573 dozens and 4,496,021 for October 1945—an increase of approxi mately 16 per cent. November 1944 inventories were about 10 per cent less than for November 1945—5,869, 860 dozens.

Table, kitchen and household glassware: Manu facturers' sales of machine-made table, kitchen and household glassware were reported at 2,684,177 dozens for the month of November 1945. This is about 4 per cent less than the 2,819,031 dozens reported for October 1945. November 1944 sales were about 13 per cent higher than for November 1945 and were reported at 3,112,221 dozens. Total sales for the 12-month period, October 1944-November 1945, are 32,221,146 dozens.

OWENS-ILLINOIS HONORS LONG-TIME EMPLOYEES

At the annual service award dinner given at the Hotel Roberts, Muncie, Indiana, on December 8, Owens-Illinois Glass Company honored forty-nine veteran employees.

The two oldest employees honored were Charles Hawk and William Jenkins, both 51-year veterans.

Speakers for the occasion were Rev. Arthur McDavitt of Muncie and Milton M. Ohlander of the company's Toledo office. Carl Smith, Muncie plant manager, reviewed the part the plant had played in the war effort.

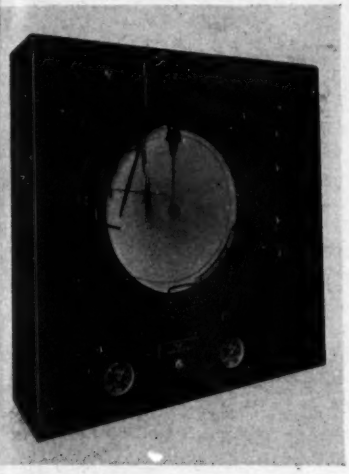
• The 1946 American Gas Association Conference on Industrial and Commercial Gas will be held in Toledo, Ohio, on March 28 and 29th at the Commodore Perry Hotel, according to a recent announcement.

NEW EQUIPMENT AND SUPPLIES

OXBORO DEVELOPS YCLELOG CONTROLLER

A recent development of the Foxboro ompany, Foxboro, Mass., is the Cycle-g Controller, an instrument to con-ol the rate of temperature increase or ecrease for batch-type processes and milar operations. The instrument also ntrols the actual processing tempera-re and duration.

CycleLog control is completely auto-



matic and no time-cams or supplemen-ary instruments are employed. Adjust-ment is made by four setting knobs on the instrument panel.

Temperatures are held at exactly the correct temperature for the correct period of time, and then the heat supply is shut off. The operator is signaled that the cycle has been completed. By reference to the instrument chart and its notations, any cycle can be exactly duplicated as desired. The controller will bring the temperature up to the desired holding point at any rate from 1 to 8 degrees F. per minute.

DOW CORNING SILICONE GREASES

Dow Corning Corporation, Midland, Michigan, announces two new silicone greases for use in ball bearings operating at speeds up to 10,000 r.p.m. and which are subject to bleeding of less than 2 per cent after 16 hours at 110° F.

One of them, DC 33, is effective over a temperature range of —940° F to 300° F. The other, DC 44, is serviceable at temperatures ranging from —4° F to 345° F.

Their low volatility and slight tendency to bleed recommend the new greases for the sealed-in lubrication of ball bearings and for the lubrication of bearings operating at abnormally high and low temperatures.

NEW AIR SEPARATOR

The Swartwout Company, 18511 Euclid Avenue, Cleveland 12, Ohio, has announced a new separator for removing moisture, oil, scale, etc., from compressed air. The new air separator is called Airfuge.

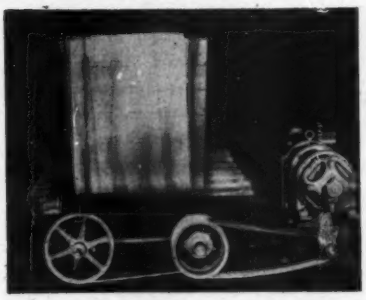
Utilizing the centrifugal principle, Airfuge is reported to be 99 per cent or more efficient in freeing air of contamination. Air entering the inlet is diverted to the inner wall of the round body and unwanted substances whirl out of the air stream and drain to the bottom. The cleaned air may be taken off horizontally or vertically from pipe-tapped ports. An integral float-operated trap releases condensate automatically.

The separator is made of high-tensile iron and the interior parts are of corrosion-resisting materials. The bottom is easily removed for cleaning. It is made in three sizes for varying capacities and with a range of pipe connection sizes.

L.A.B. PRESENTS NEW TEST TABLE

A new test table that vibrates and shakes like a freight car to test packages and products to assure their arriving in good condition has been announced by the L.A.B. Corporation of Summit, New Jersey.

Two eccentric shafts, one under each



end of a strong table, cause the table to vibrate with a circular motion in a vertical plane, and with a displacement about the same as the maximum deflection of average freight car springs and a frequence similar to their natural frequency. The shaft at one end of the table can run either synchronously or out of phase with the shaft at the other end, or at a different speed. As a result, the table has a mixed motion and a "pitch and toss" in addition to its vertical and horizontal movements. One hour's test is equal to a coast to coast freight trip.

The table size is 5′ x 5′ and has a capacity of 1000 lbs.

CATALOGUES RECEIVED

Rochester Ropes, Inc., Jamaica, New York, has recently released an edition of their house organ, "The Rope Maker", which is devoted to the glass industry.

The booklet traces the history of glass, and its front cover features a reproduction of a painting by Dominic Sindona illustrating typical nineteenth century glass blowing when window glass and all other flat types were blown in cylindrical shape before being flattened.

Illustrations of different types of glassware are included, as well as operations in the glass plant.

Island Equipment Corporation, 101 Park Avenue, New York 17, New York, has just issued a bulletin featuring their improved Power-Flex unit system.

The booklet is printed in two colors, profusely illustrated, and contains information on spot conveying, as well as details of the Power-Flex unit with complete specifications and data.

Air Reduction Sales Co., Inc., 60 East 42nd Street, New York 17, New York, has just released a booklet describing the new Wilson "Bumblebee" alternating current transformer arc welding machine.

The 16-page illustrated booklet describes 300 and 500 ampere standard and all-weather models and the new 200 ampere "Bumblebee," which has been designed to meet the demands for a small arc welder.

Cambridge Wire Cloth Co., Cambridge, Maryland, has just released Bulletin No. 79 featuring Cambridge conveying belts and wire cloth and screens.

The bulletin illustrates various types of mesh and screens and shows the Cambridge conveying belts in operation. Also included are industrial baskets, crates, trays and fixtures.

Wilson Welder & Metals Co., Inc., 60 East 42nd Street, New York 17, New York, has published a 32-page illustrated catalogue entitled, "Arc Welding Electrodes".

Designed to guide electrode users in the selection of the right electrodes for any specific job, the catalogue supplies complete data on the proper electrodes for all types of work and describes the approved welding procedures for each application.

Electrodes are recommended for use on mild steel, alloy steels, low alloy high tensile steel and stainless steels. Chemical analyses, specifications and other engineering data are supplied for each electrode.

B. F. Goodrich, Akron, Ohio, has made available a new catalogue section on its line of transmission belting.

The booklet features the company's transmission belting, "Highflex," which has a square edge and foldless hard duck transmission belt. Details of the manufacturing and testing program for each foot of this belt are given.

THE MECHANICAL STRENGTH OF GLASS . . .

(*Continued from page* 21)

major factors modifying the strength of the material at absolute zero. Fig. 1a refers to glasses and three dimensional polymers. The lack of gliding planes and the presence of strong bonds extending in all three dimensions make dissipation of dangerous stresses through viscous flow or surface diffusion impossible in the low temperature range. Strengthening becomes noticeable only above 200°C. for normal silicate glasses. On the other hand, the absence of creep makes these systems

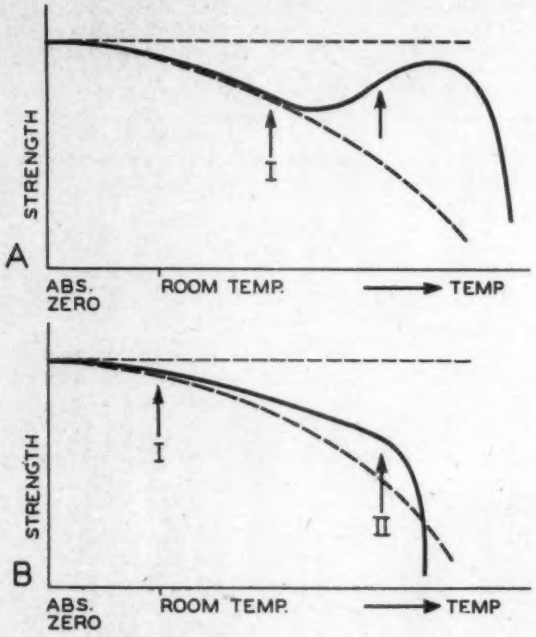
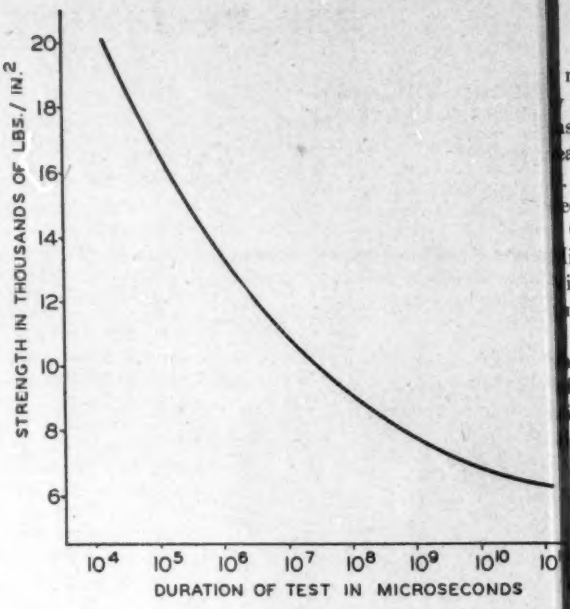


FIGURE 1

stand up to relatively high temperature until a general breakdown of the major bonds causes a rather sudden collapse. Linear polymers or metals (Fig. 1b) lack the rigidity of the materials of the first group. Their ability to dissipate maximum stress around flaws begins at relatively low temperatures. The same property leads, however, to creep and failure at temperatures below the melting point.

5. Influence of the duration of the load on the strength value. As outlined in the introduction, the so-called "fatigue," that is, the failure of glass under load of long duration, is supposed to be one of its unique features. It is well established that in static tests the time is of great importance in deciding what value of strength may be assigned to a piece of glass. In the same way the rate of loading affects the results of dynamic tests. It has been pointed out that the enormous increase in strength of glass fibers of decreasing diameter can partly be attributed to the increased rate of loading which is the result of the small area under tension.



FAILURE OF GLASS
UNDER LOADS OF LONG DURATION
(AFTER T. E BAKER)

FIGURE 2

M. Grenet[22] was the first to call attention to the influence of the time on the strength values. His bending tests of a plate glass indicated that twice the load which produces failure in several hours can be supported for one second as can be seen from the following data:

Duration of Load.	*Tensile Strength*
1 second	7.2 kg/mm²
40 minutes	4.7 "
2 hours	4.2 "
40 hours	3.3 "

In connection with the testing of bottles, several investigations have been devoted to the influence of the duration of the load upon the strength. They led to the specification of two types of pressure tests: One, the snap bursting pressure test, where the pressure is raised rapidly until the bottle bursts. It gives higher values than the sustained bursting pressure test, which corresponds closer to practical conditions. K. H. Borchard[23] found a logarithmic law, according to which the strength decreases with the duration of the load.

Another logarithmic law was devised by A. J. Holland and W. E. S. Turner.[24] They determined the effect of sustained loading on the breaking strength of sheet glass and found a nearly linear relation between the logarithm of the fracture time (t) and the logarithm of the maximum applied stress (L).

$$\log t = a + b \log L \quad \text{or,}$$
$$t = a \cdot L^b$$

The longest range of time values of stress were obtained by T. C. Baker in the Preston Laboratories[6]

(*Continued on page* 34)

THATCHER ANNOUNCES PERSONNEL CHANGES

number of personnel changes were recently announced Thatcher Manufacturing Company. John B. Miller s been named District Manager for New England with adquarters in Boston. Mr. Miller, replacing Edward Tipton who has resigned, was Sales Manager of the er & Beverage Division.

George A. Mellor, Advertising Manager, assumes Mr. iller's former position of assistant to David R. Parfitt, ice President in Charge of Sales, in addition to conuing his present advertising work.

Joseph L. Stanley, formerly handling milk accounts for e Rochester office, will transfer to the Philadelphia ffice, and Howard Blair will transfer from the New York ty office to Rochester to fill Mr. Stanley's former posion.

OWENS-CORNING APPOINTS WASHINGTON MANAGER

Named to succeed C. R. Donovan as manager of the Washington office of Owens-Corning Fiberglas Corporation, Ludlow King joins the company in this capacity.

Mr. King has recently retired from the Chemical Warfare Service in which he served as a lieutenant colonel. During his three years in the U. S. Army, he was executive officer of the Materiel Command of the Chemical Warfare Service, supervising and coordinating work of the Technical, Industrial and Supply Division. Following graduation from the U. S. Military Academy at West Point in 1930, Mr. King entered civilian life and served as an engineer in the petroleum industry, later taking up sales work in the sugar and packaging industries.

Mr. King succeeds C. R. Donovan who has resigned to establish his own firm as a Washington business consultant.

OWENS-ILLINOIS NAMES PRESCRIPTION WARE MANAGER

The appointment of Robert D. McNaull as manager of the Prescription Ware Division of the Owens-Illinois Glass Company was announced recently.

Mr. McNaull succeeds Lt. C. J. Kiger, former manager who is currently serving in the U. S. Navy. New duties are planned for Lt. Kiger when he returns to civilian life.

KNOX GLASS EXPANSION ANNOUNCED

It was recently reported that Knox Glass Associates will build a branch factory in New London, Connecticut. The new factory is expected to employ between 200 and 400 workers and will occupy from 100,000 to 150,000 square feet of space.

This new plant is believed to be the first glass container automatic production factory in New England.

BEAUDOIN REJOINS CHAS. TAYLOR SONS

Lyle C. Beaudoin has rejoined Chas. Taylor Sons Company to handle the Michigan territory from the company's Detroit branch office.

Mr. Beaudoin left the firm in 1943 to enter the service where he became a member of the 90th P.W. Detachment in North Africa. He later returned to the United States where he was re-assigned to the Army Criminal Investigation Department. He received his honorable discharge in November.

OWENS-ILLINOIS PRESENTS SOUND FILM IN COLOR

The Owens-Illinois Glass Company has produced a sound slide film in color, "Reviews and Previews", developed in the interest of the carbonated beverage industry.

The film reviews conditions in the beverage industry yesterday and today and gives a preview of what tomorrow may bring. Both cartoon and "life characters" are used.

As a refresher, the film serves to bring the driver-salesman up-to-date in his job as sales merchandiser and is of interest and value to new men being added and to servicemen returning to their jobs of selling carbonated beverages.

SALES REORGANIZATION AT COLORADO FUEL & IRON

The California Wire Cloth Corporation, West Coast subsidiary of the Colorado Fuel and Iron Corporation, will manage sales and service operations of the company on the Pacific Coast according to a recent announcement.

The territory served by the new sales arrangement will comprise the states of Washington, Oregon, California and Nevada. California Wire Cloth Company will direct the sales of all products of the following companies: The Colorado Fuel and Iron Company, Wickwire Spencer Steel Division, Wickwire Spencer Metallurgical Corporation, Coburn Trolley Track Division and American Wire Fabrics Corporation.

SYLVANIA ACQUIRES WABASH APPLIANCE CORP.

The Wabash Appliance Corporation, manufacturers of photoflash and incandescent lamps, has merged with the Wabash Photolamp Corporation and Birdseye Electric Corporation to become a wholly-owned, but independently operated, subsidiary of Sylvania Electric Products, Inc. The merger became effective January 1.

A. M. Parker remains President and General Manager of Wabash with headquarters in Brooklyn, New York. Sales staffs, sales policies, product brands and distribution outlets also remain unchanged.

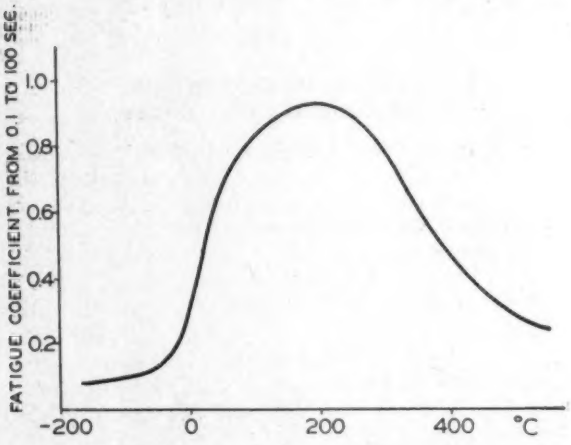
(*Continued from page* 32)

(Fig. 2). A specially designed apparatus involving electrical loading made it possible to study the strength of glass rods under loads of only 1/100 sec. duration. For this purpose loading and unloading had to be accomplished in 1/1000 of a second. The results of Baker, therefore, go much further toward the short-time end than those of earlier investigators.

It is a well established fact that the load which a glass may sustain for long periods of time or for infinite time is much smaller, only about one-third or one-fourth of that which it can carry for a second.

The understanding of this puzzling behavior of glass has been furthered by two different approaches. Work in the Preston Laboratories on the temperature coefficient of fatigue revealed that the phenomenon does not exist at very low temperatures, nor above 500°C. Fig. 3 gives the results obtained by B. Vonnegut. The numerical values for the fatigue are the ratios of the strength of a moderately short duration to the strength of long duration. Preston[6] sees proof in these results that the fatigue of glass involves a chemical reaction by participation of the adsorbed moisture layer, a view which has been expressed by A. Smekal.[12]

The second approach to an interpretation of fatigue was made by A. Smekal and his students, especially K. H. H. Müller.[15] From the shape of the fractured surface which, in practically all cases, consists of a smooth polished looking area or "mirror" and a grooved part, Smekal deduced that fracture occurs in two steps. The



FATIGUE OF GLASS
AT VARIOUS TEMPERATURES
(AFTER B. VONNEGUT)

FIGURE 3

first step is the relatively slow growth of a flaw, which leads to a smooth surface, the mirror. Propagation of the molecular crack under participation of the moisture decreases the effective cross sectional area, thus increasing the stress to a point where sudden fracture occurs. The relative size of the mirror indicates the extent to which the first slow part of the process contributes to the failure under tension. It is this phase which is affected by temperature, by the rate of loading, by surface scratches and by the environment. At the temperatu of liquid air the mirror is practically nonexistent, whi means that the slow process is inhibited. The maximu mirror size is obtained at the temperature whe "fatigue" values are highest. At higher and lower te peratures the relative size of the mirror decreases.

If one subtracts the mirror from the cross section area, one obtains that part of the cross section whi carried the total load at the moment when sudden fra ture occurred. Experiments showed that the tensi strength calculated on the basis of the grooved area a characteristic property of the glass and determined b its theoretical strength and those flaws which are stati tically distributed throughout its volume. Smekal calle this value a "constant of the material" because it wa found to remain unaffected by environment, time an rate of loading. As an example, G. Apelt's[20] measur ments of the strength of glass rods as a function of th rate of loading shall be presented. In this series glas rods of a cross section of 1.5 mm² were broken unde tension and the rate of loading was varied in ratio from 1:1000.

TABLE I

TENSILE STRENGTH OF GLASS RODS AS A FUNCTION O THE RATE OF LOADING
(AFTER G. APELT)

Reciprocal Rate of Loading sec/kg	*Tensile Strength Z kg/mm²*	*Relative Size of Mirror %*	*Correcte Tensile Strength Z_o kg/mm*
0.95	13.1	6.8	14.1
1.8	12.0	7.1	12.9
6.5	11.5	14.5	13.3
150.0	8.3	27.2	11.4
306.0	7.9	34.6	12.6
480.0	7.9	27.9	11.3
660.0	7.5	38.2	12.9
990.0	7.6	44.7	11.9

$$Z_o = Z \frac{1}{1 - \frac{S}{q}}$$

Z = tensile strength as measured
S = area of mirror
q = total cross sectional area

The first column of Table I gives the reciprocal value of the rate of loading, expressed in sec/kg. In the first experiment it took only 0.95 seconds to apply the load of 1 kg, whereas, the time required in the last experiment had been increased to 990 seconds. As a result the tensile strength, Z, decreases from 13.1 to 7.6 kg/mm² as given in the second column. At the same time, however, the nature of the fracture undergoes a change. The rapid loading produces a small mirror whose area amounts to only 6.8% of the new surface. That means that the slow part of the breaking process had not found time to proceed very far. When the load was applied slowly, nearly half of the cross section was formed by the mirror. The slow propagation of the flaw in the form of a molecular crack had gradually de-

(*Continued on page* 36)

Salute to THE GLASS INDUSTRY

During 1944-45, Union Pacific paid tribute to American industry on its radio program "Your America", broadcast each week over a nation-wide network. Representatives of 70 major industries were given the opportunity to present the dramatic story of their respective industry's contribution to the welfare of the nation.

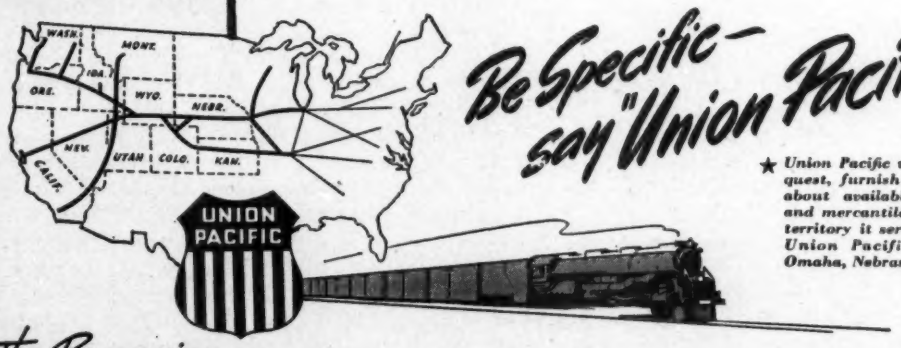
For example, on one program our guest speaker was Victor L. Hall of New York City, representing the glass industry.

Union Pacific—along with other railroads—was then engaged in moving vital wartime materials. Your industry and the nation generally knows what a tremendous task that was and how efficiently it was accomplished.

Today, Union Pacific is prepared to continue its assistance to your industry by speeding the distribution of peacetime commodities. Equipment, facilities and personnel are geared to provide unexcelled service.

A staff of trained traffic men stand ready at all times to cooperate with you.

For fast, dependable service . . . .



Be Specific— say "Union Pacific"

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The Progressive

UNION PACIFIC RAILROAD

The Strategic Middle Route

(*Continued from page* 34)

creased the effective cross-sectional area until the ultimate tensile strength of the glass had been reached. The last column contains the values of the tensile strength for the reduced cross section. This correction is justified if we agree with Smekal that at the moment of breakage only the grooved part of the cross section carried the full load. Carrying out this correction one obtains a slightly higher tensile strength Z_0 for the high speed loading, but this value remains practically constant if the load is applied for long duration.

Smekal's discrimination between a slow propagation of a submicroscopic surface flaw and the instantaneous fissure of the glass under tension provides the key for the understanding of most of the strength problems of glass.

First, it explains the importance of surface flaws because only those permit a chemical process to start at their apex, where tension reaches a maximum. Secondly, Smekal's interpretation of the shape of the fractured surface provides a convenient tool to calculate the intrinsic strength of glass; that is, the value which has to be attributed to glass as a material. Obviously, this cannot be equal to the theoretical strength as derived from estimates of the interionic forces because of the flaws present throughout the glass volume. Nevertheless, it is a strength value which is characteristic for the glass and shows the normal behavior in respect to temperature and time.

K. H. Borchard[23] published a paper dealing with the practical application of Smekal's theory to problems of the container glass industry. He proved that the results obtained by G. Apelt[26] and others of Smekal's school are not limited to glass rods, but are valid also in the case of bottles broken in the pressure test. In this case the length of the mirror was found to increase proportionally to the logarithm of the duration of the pressure. From the relative size of the smooth area he could deduce whether a container had failed due to the pressure of long duration or through an instantaneous shock.

It is of theoretical and of some practical interest to learn whether there exists a "safe load" for glass; that is, a load which can be supported for an infinite time. A little reflection shows that for loads small in comparison with the short-time breaking strength, the chemical reaction of the glass with the environment would alone be responsible for the failure. If one extrapolates a time-strength curve to find a zero load for infinite time, one merely states that the material glass is not in equilibrium with the atmosphere or better with its water vapor content.

The extrapolation to extremely short times is theoretically limited to the time necessary to propagate the mechanical impulse. It is of the order of microseconds (1 microsecond = 1 millionth of a second) if one assumes that the shock propagation reaches its theoretical limit, that of the sound wave.

The sound velocity in glass is approximately 5000 m. per sec., but the actual fracture propagates with only one third of this speed and is rather independent of the rate with which the shock is applied. Independent measurements; namely, those of H. Schardin and W. Struth and those of F. E. Barstow and H. E. Edgerton [28] agre within a few percent and give values of about 15 m/sec.

6. *The influence of the environment on the streng of glass.* The work of Preston on the fatigue of gla as a function of temperature and the method of Smek to calculate the upper tensile strength of a glass by eli inating the action of surface flaws give evidence that is not the mere passage of time which causes a glass fail under loads of long duration. Both are stron indications for a reaction with the water film or wi the moisture of the air as responsible for the fatigue glass.

In this chapter we shall try to present a picture such a reaction based on our present knowledge of th surface chemistry of silicate glasses.

It seems to be well established that there is no funda mental difference between the effect of moisture on th strength of silicate glasses and pure silica. S. Schu kow[29] found that fibers made from pure silica behav very similarly to those studied by A. A. Griffith whic were made from a normal soda-lime glass. They po sessed their greatest strength right after drawing. In ai they lose strength and finally approach the same valu as those wetted by water.

The effect of humidity or of liquids in contact wit the glass surface is not limited to very thin fibers. H Milligan[30] tested the bending strength of glass rods wit surface scratches at the place of maximum tension. Wet ting the crack with water decreased the strength of th rods 20% of that in dry air. Wetting with paraffin oi increased the average strength value 17%. D. G. Moor and W. N. Harrison[31] examined the effect of humidity o enamel fibers 0.65 to 0.85 mm. in diameter and found that their tensile strength decreased about 25% when the humidity of the environment was increased from 50% to 90%.

Coated with paraffin this acid-resisting enamel had a tensile strength of 34 kg/mm^2. Under kerosene this value was found to be 25 kg/mm^2 and could be raised to 28 kg/mm^2 if the kerosene had been dried with calcium chloride. Under water the tensile strength was the lowest, 19 kg/mm^2.

There can be no doubt that water plays the same role during a grinding operation by aiding the abrasive to chip off small pieces from the surface. This is brought out nicely in the work of K. von Stoesser,[32] who determined the loss of glass as a function of the grinding speed (Fig. 4). The presence of paraffin oil prevents the action of moisture and produces the lowest values. Additional work concerning the abrasion hardness of glass in different media will be discussed in the chapter VII.

No matter what the composition of a silicate glass is, the propagation of a surface flaw must necessarily involve the breakage of Si-O-Si bonds. As they are the strongest bonds in the glass structure, the speed of rupture is governed by the activation energy of this process. This does not mean that other constituents of the glass are without influence. The presence of alkali and other basic oxides, e.g., decreases the number of Si-O-Si bonds per unit volume. The hydrolysis of an alkali containing glass should be somewhat faster than that of pure silica

(*Continued on page* 38)

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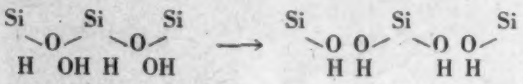
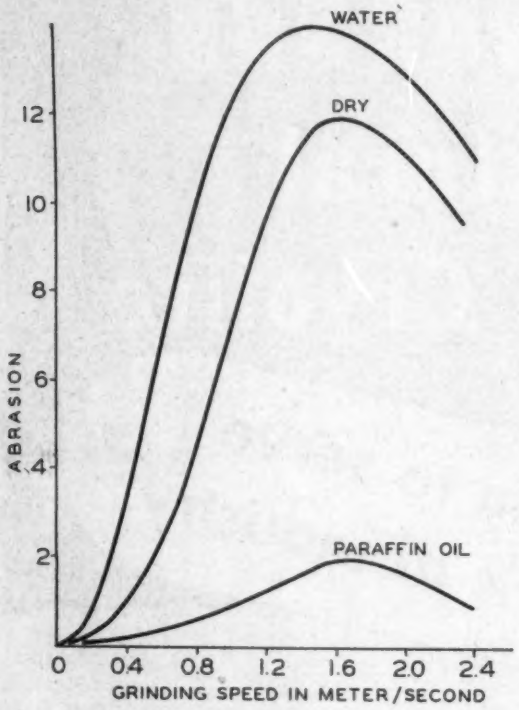
CINCINNATI • MINNEAPOLIS • WYANDOTTE • TACOMA

(*Continued from page* 36)

because of the presence of more OH^- ions in the attacking film. On the other hand, aluminum ions must delay the attack by "poisoning" the reaction. All these factors, however, produce only variations of the principle process



in which the adsorbed water breaks the Si-O-Si bonds. The effect of this hydrolysis is twofold: (a) It causes



INFLUENCE OF THE MEDIUM ON THE ABRASION OF GLASS
(AFTER STOESSER)

FIGURE 4

a molecular crack to propagate, thus decreasing the effective cross section. (b) The increase in volume of the dehydrated layer drives the walls asunder, thus increasing the force which acts to produce fracture.

The delayed crazing of glazed tiles and other ceramic products is the result of moisture expansion. The porosity of ceramic articles permits moisture to react with the body throughout its mass and the volume increase ruptures the glaze.

Even if it is not yet possible to give details concerning the rate of hydrolysis, we can readily see that increasing temperature must produce two antagonistic effects which lead to an optimum temperature for the reaction of glasses with the moisture of the atmosphere. (a) Increasing the temperature speeds up the reaction rate. (b) Increasing temperature decreases the stability of the reaction product, shifting the hydrolysis equilibrium to the side of the anhydrous silica.

$$SiO_2 + 2\,H_2O \rightleftarrows Si(OH)_4$$

Studies on the base exchange at the surface of soda-lime glasses by H. S. Williams and W. A. Weyl[33] led to the conclusion that a "hydrogen glass" becomes instable between 400-500°C. At this temperature the reaction described by the above equation is shifted to the left side, water is driven off and Si-O-Si bonds are reformed. Above 500°C., therefore, the moisture should have no effect on the tensile strength.

This chemical picture agrees very well with the results obtained by B. Vonnegut and the interpretation given by F. W. Preston,[6] who wrote, "The meaning of this (that is, the maximum of fatigue of glass at +200°C.) seems to be that fatigue is a phenomenon of the adsorbed moisture layer. At low temperatures the layer is thick but very inactive. At high temperatures it is very thin, being driven off by evaporation. In the intermediate range, where we normally experimented with glass, the layer is both thick and active, and fatigue is rapid."

There is one aspect of the cooperation of the chemical action of water with the mechanical forces which deserves further explanation. The fact that glasses are covered with a strongly adherent film of moisture is well established and understood. It is more difficult, however, to explain how the water molecules penetrate fast enough into the interior of a propagating crack to be of use. Only at the apex of a flaw where tension is the highest can the water molecules be effective.

Fortunately there exists a valuable piece of experimental work dealing with the spreading of fluids on a glass surface which proves that the speed of a monomolecular layer of a liquid spreading on a glass surface is extremely high. We are well acquainted with those phenomena which deal with the spreading of monomolecular layers of oils or camphor on the surface of water. W. B. Hardy[34] found that the same phenomena exist on a glass surface. The method he used for detecting the monomolecular film is very original. Monomolecular layers are invisible and are too thin to produce interference colors. W. B. Hardy and J. K. Hardy[35] had found that clean glass surfaces adhere strongly and exhibit high friction when rubbed against each other. A molecular film of another substance prevents the seizing of the glass and acts as a lubricant. Pulling a watch-glass over the clean surface of plate glass requires a relatively strong force. If one touches a corner of the plate glass with acetic acid, friction is decreased immediately. A monomolecular layer of CH_3-COOH spreads over the glass surface practically instantaneously and acts as a lubricant, but the bulk of the liquid remains in the form of a droplet. It is not improbable that the speed of the slow (mirror forming) part of fracture is governed by the speed of spreading the water layer across the newly formed surface.

It is of great practical interest and of theoretical significance to find out about the reversibility of this "corrosion process." The experiments of L. V. Black[36] indicate that glass which had been loaded for a long period of time is restored to very near its original strength as soon as the load has been removed. The restoration of the original strength must mean that the crack which must have penetrated into the glass to a

(*Continued on page* 48)

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GLASS CONTAINER MANUFACTURERS INSTITUTE MEETS IN MIAMI . . .
(*Continued from page* 23)

report, two meetings had been held by the Committee. In the interests of brevity, he submitted seven points covered at the Committee's initial meeting in Cleveland on June 27, 1945. The summary of this meeting is as follows: "1) Mr. F. E. Fuller addressed us, outlining the organization of the Institute and the Committee. 2) We recommended the employment of the Preston Laboratories as the agency to carry on certain investigations for the Committee. 3) We recommended the retention of Mr. Bert W. Hendrickson as legal counsel for personal injury suits involving alleged broken bottles. 4) We adopted a table of charges for services in connection with the above type of suits. 5) We adopted the standard testing procedure and related data promulgated by the Glass Container Association (dissolved). 6) We established four committee meetings per year. 7) We recommended the sale of standard annealing discs to reputable interests up to a point where a certain reserve was maintained for use of member companies."

With regard to the Committee's work on injury claims, Dr. Lyon approached this phase of the Committee's work stating that, "The Standard Testing Procedure work was initially instituted because of the need for an established testing procedure to ensure, so far as practically possible, that glass containers offered for use by the public are of adequate strength."

The work of Dr. Gehring in testifying in claims for personal injury caused by allegedly defective bottles was outlined, as well as the examination of broken bottles both in pending claims and lawsuits.

Cooperation with the bottlers in connection with injury claims was also touched upon by Chairman Lyon. However, his statement on this was very brief since Bert W. Hendrickson, Committee Counsel, made a full report to the assembled container manufacturers.

Turning to Research and Investigation, Dr. Lyon stated, "As the pressure of setting up standard tests has been relieved, the Committee has been able to turn its thoughts toward improvement of container strength. As funds have become available, projects have been assigned to the Preston Laboratories for study. The investigation of the nature of cords and a method of identifying them and evaluating their effect on mechanical strength has been carried for a number of years. Through the cooperation of member companies with the Preston Laboratories, we have made considerable progress in this field. The centrifuge-density apparatus in the Plant Laboratory serves to give information as to the nature and probable cause of most types of cord. This work may be tied in with a series of chemical analyses to give more specific information. The apparatus is fairly expensive and the method somewhat complex so that only a few of our largest companies, or those for whom the existence of cord is a particular problem, can justify the ownership of one. However, the apparatus at the Preston Laboratories is available to the industry, usually without charge, as a service.

"Our report from the Preston Laboratories shows that 67 samples were run through the centrifuge during the past several months. These samples were from the plants of fourteen different companies.

"As an outgrowth of the centrifuge work and with th cooperation of the companies represented on our Com mittee, the Laboratories have built, for sale, a simpl apparatus for the rapid and accurate determination o glass densities. The method of keeping track of change in glass composition by changes in density has bee practiced in the industry for a number of years. Althoug it does not provide a complete answer, the method doe indicate changes in soda, lime or sand. Some of ou people have related these changes to the occurrence o cord, and others have been able to show a relationshi between glass density and per cent pack.

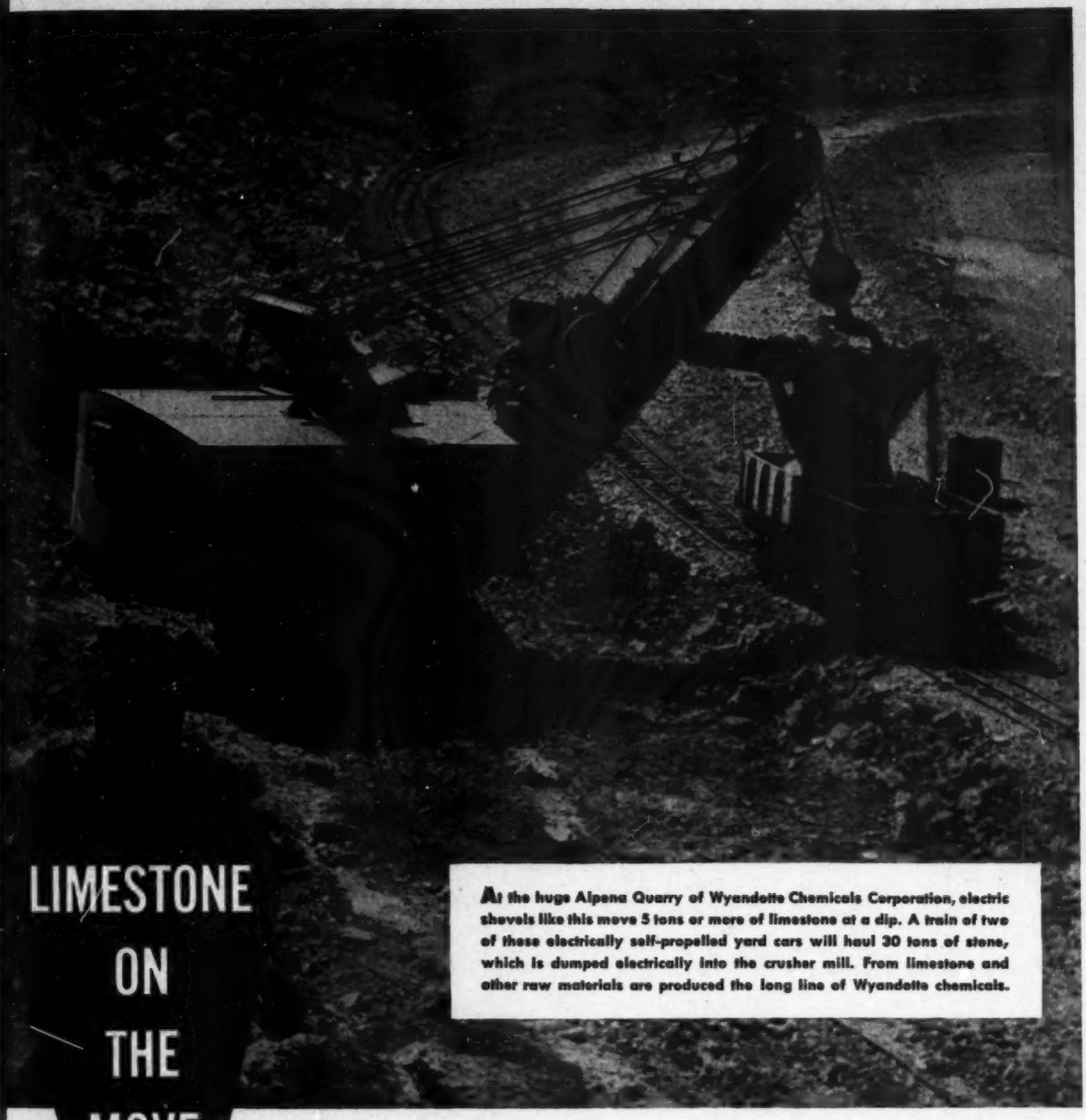
"Members of the Preston Laboratories' staff have bee occupied in assisting container plants in setting up thi method of control and in making density measurement for them as a matter of service. Projected work in thi field includes a study of further simple and fast method of distinguishing which of several possible changes in composition are the cause of the specific density change observed."

With regard to Impact Research, Dr. Lyon was quite thorough in his outline of the problems involved and efforts to overcome or minimize impact breakage. He stated in part, "This is a tough problem. The impact breakage of any material is not too well understood and that of brittle materials, such as glass, even less. Such information as we have is of a practical nature rather than fundamental physical or mechanical theory. Our practical information is important, but we are reaching the limit of its usefulness. We need fundamental research and, in my opinion, it is worth the cost, even if results come slowly. We cannot expect spectacular discoveries within a year or two.

"Within the past year, the Preston Laboratories have been orienting or training a research physicist and attempting to formulate the fundamental problems and lines of attack. So far, the results have not been impressive. They are approaching the problem from the point of view that the absorption and transfer of energy is one of the important fundamentals. The concentration of the load or stress also is important. In general, thin walled bottles are strong because the walls flex and the energy is absorbed within the bottle. Thick walled bottles are rigid, and often break because the load or stress is concentrated. The practical approach to impact and the devising of clever simulating impacting tests or machines give valuable information in specific applications, but they often do not take into account how much of the energy is absorbed by the impacting object, how much within the bottle, and how much by the support on the other side of the bottle. Neither do they give fundamental information on the vibratory nature of the energy and its transmission, and on the basic requirements of a bottle in order for it to stand all sorts of impacts.

"Some side issues or lines of attack have been explored. The apparent strength of sheet glass rigidly supported and broken by pressing steel balls of various sizes against it has been studied and the data published in the technical press. This is of immediate practical importance only because of the fact that a container may be broken by a load or impact having a small area of contact. The real value of the work lies in fundamental interpretations of

(*Continued on page* 42)



LIMESTONE ON THE MOVE

At the huge Alpena Quarry of Wyandotte Chemicals Corporation, electric shovels like this move 5 tons or more of limestone at a dip. A train of two of these electrically self-propelled yard cars will haul 30 tons of stone, which is dumped electrically into the crusher mill. From limestone and other raw materials are produced the long line of Wyandotte chemicals.

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GLASS CONTAINER MANUFACTURERS INSTITUTE MEETS IN MIAMI . . .

(*Continued from page* 40)

the nature of breakage under a static as distinguished from a dynamic load.

"Another contemplated line of attack is the taking of high speed photographs of glass breaking under a dynamic load. Another is the study of the effect of vibrations. Also, the role of distribution and wall thickness is being studied along with methods of measuring wall thickness. In this connection, it is important to have available various samples of a standard type bottle having a great variety of types of distribution characteristic of various types of forming machines. Mr. Hall's letter to the industry of October 17 requesting standard 4/5 quart liquor bottles, WPB Exhibit A-2-a, Schedule A, L-103, is for the purpose of obtaining samples representing all types of manufacture and distribution, all, we assume, adequate to meet the demands of the trade.

"In addition to the Preston fundamental research, the Committee is making a study of a simulative filling-line impact test. Although in the end the laboratory research will undoubtedly offer the best lead for designing and making stronger bottles, we do have the practical problem of ascertaining whether present bottles are going to go through a typical filling-line without breakage. We want to know this before we ship the bottles, and the best plan seems to be to work out a practical simulative filling-line test. The Laboratories may cooperate in this but their main effort will be devoted to fundamentals rather than to simulative gadgets."

Other services of the Preston Laboratories were outlined and it was recommended that the testing procedure promulgated by the dissolved Glass Container Association be adopted.

Attempts are being made to compile a list of other tests in various plants which will be made available to the industry.

Standards and Finishes

George M. Stuntz of Anchor Hocking Glass Corporation as Committee Chairman made his report for the Committee on Standards and Finishes. This Committee, from a company standpoint, is composed of seven manufacturers, three glass companies including Anchor Hocking who also manufactures closures, three closure manufacturers and the Overmyer Mould Company. Participating companies, Hazel-Atlas Glass Company, Owens-Illinois Glass Company and Thatcher Manufacturing Company, also have designated representatives to attend meetings as observers.

Two meetings have been held by this Committee to date and at the first meeting, a Sub-Committee was appointed to study tolerances and gauge practices. At the second meeting, the Committee accepted and approved recommendations of the Sub-Committee on tolerances and gauge practices and reported in detail to the membership these recommendations.

It was reported that with respect to future activities, the Committee will undoubtedly give its attention to work on standards of neck diameters. This factor is felt to be of considerable importance in connection with standards and simplification and of real value to the industry and users of glass containers.

Traffic

That matters pertaining to traffic, the shipment of finished products, supplies and materials, have become increasingly complex was indicated in an introduction to the Traffic Committee's report by B. H. Taylor, G.C.M.I. Traffic Director. In this forward, Mr. Taylor stated, "Public interest and particularly shipper interest in transportation, in its many ramifications, has been continuous for several decades, but in all this period there probably has never been a time when the subject merited more watchful attention by industry than now.

"The transition which has occurred in the thinking and practices of both sellers and buyers of transportation services and by the Government, stemming largely from developments and experience gained during the war emergency, has made it clear there has arisen a complex problem of adjustment to post-war conditions.

"The direction this adjustment will take has not yet crystalized sufficiently to foresee its ultimate course. Doubtless some of it will reflect understandings reached by negotiations between suppliers and users of transportation which will be of a voluntary nature while other phases of it will likely be by prescription of regulatory bodies and by legislation yet to be enacted.

"From such knowledge as the Traffic Committee and its non-member consultants have on what appears to be in the making, it believes the scope of its permitted activities, for and in behalf of the glass container industry as a whole, as spelled out in the Institute's Code of Regulations, is sufficient to enable it and its advisors to function on pending matters of transportation and traffic for the best interest of the industry."

Six glass companies, including Dominion Glass Company of Montreal, Canada, are represented on the Traffic Committee. At the two meetings held by this Committee since its organization, participating companies were represented by U. E. McFarland, Owens-Illinois Glass Company; J. L. Sprowls, Hazel-Atlas Glass Company; and A. W. Stebbins, Thatcher Manufacturing Company.

Various traffic problems were touched upon by Mr. Taylor in his report and since all traffic matters usually seem to be quite complicated, we will not attempt in this report to present the details of Mr. Taylor's discussion except in the case of the Interstate Commerce Commission ruling relating to lowering of class freight rates by ten per cent in certain sections of the country while increasing rates by a like percentage on Eastern Territory. Although Mr. Taylor stated that after careful study it is felt that the glass container industry would not be adversely affected by this ruling because of the wide interest in this subject, Mr. Taylor's report on the matter is quoted in full.

Referring to two orders of the ICC (Dockets 28300 and 28310), he stated, "These two investigation proceedings were instituted by the Interstate Commerce Commission in July 1939. In Docket No. 28300, the purpose was to determine whether the intraterritorial and interterritorial class rates in Eastern, Southern and Western territories were unreasonable or otherwise unlawful. The order invoking the investigation specifically exempeted the class rates in Mountain-Pacific Territory and those between that territory and the remainder of

(*Continued on page* 47)

SURFACE COMBUSTION

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SURFACE COMBUSTION

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INVENTIONS AND INVENTORS . . .

(*Continued from page 27*)

Patent No. 2,390,910 is an invention of William E. Aksomitas and assigned to the Hartford Empire Company. The patent shows a method of tempering bottles.

In order to obtain a greater cooling effect than is possible with air jets, it has been proposed to add water to the air so as to form a spray. One of the difficulties in using a water spray of this kind is that the water is likely to accumulate in spots, particularly in the bottom of the container, which may damage the surface of the glass. This patent proposes a method of tempering a bottle by a mixture of air and water and after the bottle has been cooled to the desired extent, then reducing the amount of water or cutting it off entirely. Thus the final cooling of the bottle will be by air alone or by air with a very small amount of moisture.

As shown in Fig. 5, a nozzle 10 is provided with a series of jets 53. The nozzle is carried by a head 15 which is reciprocated vertically by a piston 18 and a cylinder 19. The drawing shows the nozzle in operating position. Air is supplied to the nozzle through a pipe 32 controlled by a valve 34. The water supply is controlled by a needle valve 43 which seats in the bottom of a tube 40 carried by the head 15. Water is admitted thru a pipe 41 and the needle valve is adjusted by the chain 51. The bottle is carried on a rotating head 28. By this construction both air and water are admitted to the nozzle 10 at first, and then the water is reduced in volume or cut off as may be preferred.

Glass Wool and Fiber

Patent No. 2,390,370 was assigned to Corning Glass Works by James F. Hyde. This invention relates to coatings for glass fibers, particularly when to be formed into yarn. It is customary to apply a coating, commonly called a binding fluid, to glass fibers before they are made into a strand or thread. The object of this is to bind the fibers together and also to provide lubrication to prevent abrasion of one fiber by another. It requires very delicate workmanship in order to obtain a binding fluid which will have the desired characteristics and still permit the thread or yarn to be unwound without injury.

The patent is directed to a coating material comprising one or more compounds selected from the class consisting of hydrolyzable organo-silicanes and hydrolysis products and their polymerized hydrolysis products. A large number of suitable materials are suggested. One composition which has been found satisfactory consists of Stoddard solvent or toluene to yield approximately 10% solution when mixed with liquid phenyl ethyl polysiloxane. This liquid may be applied to the fibers by drawing them across a saturated pad as the fibers are being drawn.

• Harold Wandling, Sr., plant engineer for the Owens-Illinois Glass Company branch at Terre Haute, Indiana, was killed in an automobile accident on December 13. Mr. Wandling had been connected with Owens-Illinois for a number of years.

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CERAMIC ASSOCIATION OF NEW JERSEY HOLDS MEETING

The Ceramic Association of New Jersey held its Annual Meeting at Rutgers University on December 14, 1945. Fred Bently, President of the Association, made an address which was followed by the presentation of a number of papers. The papers were "Specialized Ceramic Parts Applied to the German Communication Industry" by Lt. Col. Richard Ranger, Signal Corps, Fort Monmouth, New Jersey, and C. L. Snyder, General Ceramics and Steatite Corp.; "Electronic Instrumentation" by R. F. Roberts, Brown Instrument Division, Minneapolis-Honeywell Regulator Company; "Manufacture of Laboratory Glassware" by J. J. Moran, Kimble Glass Company; "Infra-Red Drying and Other Innovations in Hotel China Manufacture" by R. E. Gould, Buffalo Pottery Company; "Survey of a Few Refractories Problems" by R. E. Birch, Harbison-Walker Refractories Company; and "Control of Tunnel Kilns" by Philip Dressler, Swindell-Dressler Company.

Also on the program was the presentation of a portrait of Dr. Cullen W. Parmalee to the University and the installation of officers.

NEW GLASS-PLASTIC MATERIAL DESCRIBED

At the recent annual meeting of the American Institute of Chemical Engineers, a paper was presented by H. W. Collins, Director of the research laboratories of Owens-Corning Fiberglas Corporation.

The paper, prepared jointly by Mr. Collins and Games Slayter, described a glass-reinforced plastic material that possesses greater strength than the structural metals, that won't corrode, that is dimensionally stable and that can be fabricated without costly dies.

The strength properties attainable with glass-reinforced plastics are: tension, 76,000 pounds per square inch; compression, 68,000 pounds per square inch; flexure, 112,000 pounds per square inch; impact, 55 foot pounds per inch of notch; modulus of elasticity, 4,000,000 pounds per square inch.

The material was widely used in military aircraft parts and equipment throughout the war and many peace-time applications are foreseen in the construction of civilian aircraft and in other fields.

WESTINGHOUSE DEVELOPS NEW LUMEN LAMP

A recently developed 60,000 lumen lamp has recently been announced by Westinghouse Lamp Division, Bloomfield, New Jersey. The 1000-watt unit has a lumen-per-watt efficiency half again as good as the three sizes of the mercury-vapor lamps available for use without special cooling systems (100, 400 and 3000-watts). This increased efficiency is a result of an increase of about four times in pressure of the mercury vapor. Lamps of this rating have previously had to be water-cooled.

The light is created in an arc stream about the shape and diameter of a cigarettte and twice as long. It is enclosed in a quartz housing, in turn surrounded by a hard-glass exterior. Overall the lamp is only 14 inches long and less than four inches in diameter.

AMERICAN OPTICAL ANNOUNCES NEW GLASS

A new heat-absorbing, color-transmitting glass, particularly adaptable for use in the motion picture and television fields, has been made known by the American Optical Company.

Dr. E. D. Tillyer, Research Director, said the new glass, when used as a heat screen in a projector, permits the projection of motion and still pictures in their original colors thus permitting pictures to be reproduced on a screen as they are taken. At the same time, he said, the glass absorbs heat emitted by the light source so that films and slides are protected against damage or burning. This insulating property enables film editors and educators to study a specified projected scene by stopping the projector and relying on the glass to protect the film.

Dr. E. D. Tillyer, American Optical Company's Research Director, demonstrates how the new heat-absorbing, color-transmitting glass protects a film or slide against heat emitted by the light of a projector.

Development of the glass, Dr. Tillyer announced, makes possible improved, safe color projection on an extended scale in homes, schools, theaters and stores. The new glass, he added, absorbs approximately 90 per cent of infrared (heat) radiations and transmits approximately 85 per cent of light out of a possible 92 per cent. The glass transmits color accurately, is chemically stable, resists weathering without requiring a surfacing treatment and can be molded, ground and polished, and fabricated like ordinary glass. It is formed from carefully balanced proportions of phosphorous, aluminum and silicon oxides, supplemented by various conditioning ingredients together with ferrous iron as the heat-absorbing agent.

The new glass was developed when, at the outbreak of the war, this type glass could no longer be imported from Germany. American Optical glass technologists intensified their development of a new heat screen based on earlier research and have now perfected a composition that is superior to the German glass.

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THE WELDING OF GLASS TO METAL . . .

(*Continued from page* 24)

ful application of the metal-spraying process, namely the attachment of metal articles to glass by soldering. The illustration (Fig. 1) shows a typical heater—actually one of French manufacture. The glass plates are held in a metal frame, and the base is a substantial block of moulded glass with a textured surface. Toughened glass, preheated to 300° C, as to electrical heaters, must be used. The area upon which soldering is to take place is first sprayed with aluminum as already described, except that the thickness of the aluminum is made about double that needed for the strip element in the heaters. Subsequently, without again preheating, this area of aluminum is sprayed with a thin coat of copper from the "Schoop" Gun, the copper patch being preferably a little smaller than the aluminum. The surface of the copper and the soldering surface of the article to be attached are then tinned with solder, after which the two are sweated together in the usual way. For these soldering operations it is necessary to use a flux entirely free from acid, such as pure resin. The method may, of course, be used for joining together two pieces of glass by soldering.

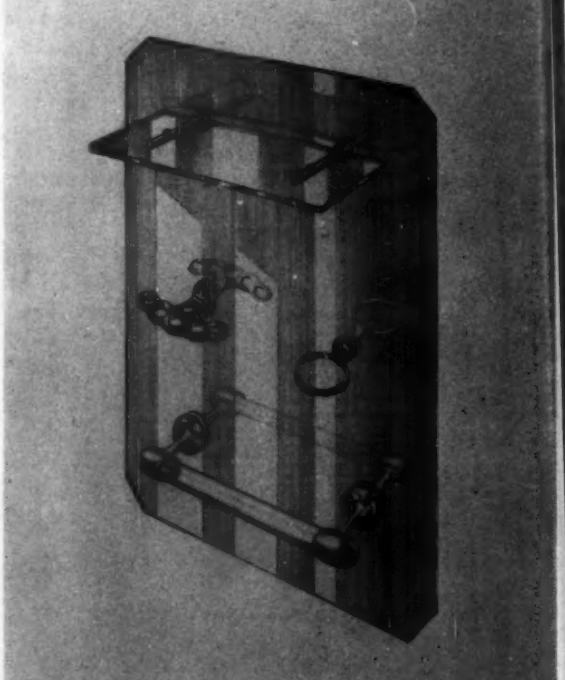

Fig. 2

Tests on joints made in this way have demonstrated the surprising strength of the bond between the sprayed metal and the glass. Tests to destruction have always resulted in fracture of the glass, out of which pieces are torn without the metal-to-glass bond giving way at all.

(*Continued on page* 51)

LASS CONTAINER MANUFACTURERS NSTITUTE MEETS IN MIAMI . . .

(Continued from page 42)

he United States. In Docket No. 28310, the investigation as an inquiry into and concerning the various different atings and carload minima and the varying percentage elationships of lower classes to the first class rate now n effect in each of the four classifications territories; amely, Official, Illinois, Southern and Western. It is companion to and necessarily a part of the investigaion ordered in Docket No. 28300.

"The Commission released its first findings in these roceedings on May 14, 1945. These findings and accompanying orders are incorporated in one report of ome 700 pages, the substance of which is that a single lassification unifying the ratings, carload minima and ercentage relationships of lower classes to the first lass rate are required. Further, that the class rates hemselves should be adjusted temporarily by increasing hose now in effect in Eastern Territory by 10 per cent nd concurrently reducing those in effect within Southern, outhwestern and that part of Western territory covered by the order; also interterritorily between those territories and between those territories and Eastern Territory by 10 per cent. This is to be only an interim adjustment, there being further ordered established an ultimate single scale of class rates to become effective within and between all of the aforesaid territories, at some later date. The interim adjustment as now ordered is to become effective January 1, 1946.

"The Committee reviewed the prescribed interim adjustment and after an analysis of the changes in rates that would be made, concluded that the glass container industry would not be adversely affected. This is because glass bottles, jar, jelly glasses, bottle caps and closures, sand, soda ash, lime, limestone, feldspar, aplite, silicate of soda, coal, fuel oil, paper and corrugated fibre boxes, move within and between all of the rate territorries involved in the proceedings either on exceptions to classification ratings or are published as specific point to point or group to group commodity rates which are specifically exempt in the order. The glass and closure industries have been kept fully informed of the developments in these two cases.

"The Committee does not believe that the Commission's orders as they now stand represent the final disposition of these two cases. Many carriers are contending that the orders will bring about unequal and unfair treatment to them by the Commission. Numerous shippers, localities and regions are complaining that the resultant rates will be discriminatory and that there is no justification for them. It is likely the state governments and civic organizations in some regions and perhaps some carriers will test in the Courts the Commission's power to enforce its orders in the light of the record before it.

"While, as stated, the interim class rate adjustment as it is now required to become effective January 1, 1946, will not, on the whole, adversely affect the freight bill of the glass container industry, it is certain the industry will have a vital transportation cost interest in a uniform classification and in any permanent single scale of class rates which will have nation-wide application. The effective date of the latter depends entirely on the date of adoption and publication of the former and there is considerable speculation when this will be. Because of the immense amount of work to be done by the railroad classification committees and the many public hearings to be conducted, a good guess would be not sooner than two years hence. This, of course, is on the assumption the Commission's orders are not enjoined.

"Whatever happens, the Committee is certain it will find itself extremely busy in these rate and classification cases from here on out."

Other traffic matters reported on were the proposal of Eastern and Southern railroads to retain heavy freight car loading by granting incentive rates, the packaging of glass containers and glass packed products and the matter of an increase in demurrage charges on covered hopper cars and charges for spotting cars.

Market Research and Promotion

Francis H. May, Foster-Forbes Glasss Company and Chairman of the Committee on Market Research and Promotion, made the briefest report of the meeting. Mr. May merely stated that no meetinng of his Committee had been scheduled up to the time of his report for two reasons. One, that he felt with the great number of other meetings which members were called upon to attend during the past six months, it seemed inadvisable to call his Committee together and Mr. May added, "I have felt that the Institute staff has had all it could properly handle in assisting the various technical committees in organizing their activities."

Mr. May further stated that it was his intention to call a meeting shortly after January 1, feeling that the general situation both within the industry and with regard to related matters would be more propitious.

Technical Work On Glass Packed Products

The report of the Technical Committee on Glass Packed Products was presented by its Chairman, M. H. Raney of Anchor Hocking Glass Corporation.

The report, Mr. Raney stated, was prepared by Dr. W. B. Esselen, Jr., and Dr. C. R. Fellers of Massachusettes State College where this technical work is being carried on under the G.C.M.I. Fellowship.

Dr. Esselen gave a rather detailed review of the work which has been done and outlined future activities.

Concluding the meeting, Henry W. Seney of Welles, Kelsey, Fuller, Cobourn & Harrington, discussed federal tax aspects of the recent Hartford-Empire royalty settlement.

ALBERT S. ZOPFI OF LACLEDE-CHRISTY SUCCUMBS

Albert S. Zopfi of Laclede-Christy died at his home on November 16 at the age of 71. Mr. Zopfi had been confined to his home for the past several months because of illness.

Mr. Zopfi had spent the greater part of his life in connection with the manufacture and sale of clay products used in the glass industry. He became Secretary and Treasurer of Buckeye Clay Pot Company at the time of its incorporation in 1909 and remained in that position until its consolidation with the Laclede-Christy Clay Products Company in 1931. He then became Manager of the Glass Pot Division.

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THE MECHANICAL STRENGTH OF GLASS . . .

(*Continued from page* 38)

certain depth began to lose its dangerous character as soon as the load had been removed. Experiments of M. W. Jones and J. M. Blair[37] concerning the cutting of glass with a diamond confirm the findings of L. W. Black. These authors found that a freshly cut glass plate was much weaker than one which was tested 1 days after the cutting with the diamond. Closer examination revealed that the strength increases very fast in the first two days and then more slowly. We must remember that the energy to produce the new surface is composed of two parts: The mechanical forces acting to separate the Si-O-Si bonds and the chemical forces breaking the Si-O-Si bonds through hydrolysis. It is characteristic for the breaking process that neither one of these two parts could by itself accomplish its aim. The glass could stand the load infinitely if corrosion would be excluded. Hydrolysis, on the other hand, would not proceed that fast if not substantially aided by the mechanical forces. Therefore, if one of the two actions is interrupted, the strength increases again. The action of hydrolysis disappears at elevated temperatures and the fatigue of glass decreases. If the mechanical load is removed, the two surfaces recombine, and the water present is dissipated in the glass structure in the form of OH^- groups.

In order to understand the cooperation between mechanical and chemical forces in breaking a glass at room temperature, we have to consider the elementary process of separating two ions, e.g., a silicon ion and an oxygen ion. At absolute zero we have to apply the full amount of energy to sever this bond by mechanical tension alone. At room temperature the thermal vibration of the two ions has to be taken into consideration. Their motion as a function of time will sometimes aid the mechanical force F and has to be added. At other times it will counteract this force and strengthen the Si-O-bond. The value of the thermal energy E, not only its direction, will vary with time. Nothing will happen to the Si-O-bond until the value of E exceeds that given by the equation

$$F + E = Q$$

where Q is the bond strength between Si and O which has to be overcome in order to bring about separation. The probability for an ion to exceed this energy value E depends strongly on the absolute temperature. The exact law can be derived by statistical physics and leads to the probability function $e^{-\frac{E}{T}}$. In the low temperature region the value of this expression is extremely small, and it will take a long time until a certain ion reaches the energy E. In other words, at low temperatures the energy for rupture has to be supplied by the mechanical force alone, and the latter has to be that of the bond strength

$$F = Q$$

The loosening and tightening of the Si-O-Si bond as a function of time is also affected by the presence of H_2O. With the electric field of the water dipole superimposed on the mechanical field, the probability for the energy of an ion to exceed E is increased. The opening of

Si-O-Si bonds under formation of Si-OH groups increases in frequency, whereas their closing becomes less probable. This is the situation around room temperature. At high temperatures where an ion reaches the E value very frequently by thermal energy alone the effect of water will be negligible, partly because of the decreased stability of Si-OH groups, partly because the separation of the two Si when forming Si-OH, can be overcome by the increased thermal vibration and the Si-O-Si bond can reform.

It should be mentioned here that the effect of water on the tensile strength of silicates can be treated formally by introducing the surface energies of a "clean" and a hydrated silicate surface. According to J. B. Obrimow,[38] the surface energy of mica, if measured by cleaving in vacuo, is about ten times higher than in air. A similar ratio can also be expected for glasses. Because of the exothermic process of hydrolysis or of heat of wetting, only about 375 ergs are required to produce 1 cm^2 of new surface. If, however, the cleavage is carried out in vacuo, where the full valence forces have to be overcome, 4,500 ergs were found necessary to produce 1 cm^2 of the very active unsaturated surface. E. Orowan approached the problem of fatigue of glasses on this basis and was thus able to calculate the load which a glass should be able to support infinitely.

For this purpose Orowan[39] used the formula which Griffith derived for the tensile strength F of a brittle isotropic solid whose modulus of elasticity is E and whose surface energy is σ. If c is the depth of the most dangerous crack, then

$$F = \sqrt{\frac{2\sigma E}{\pi c}}$$

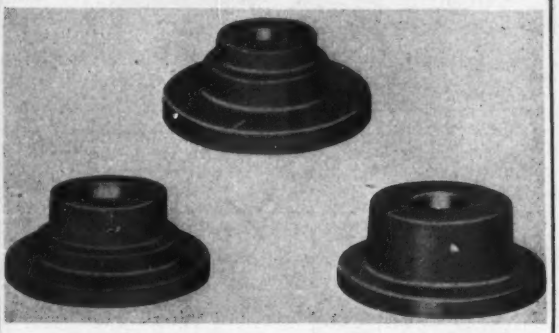
Broken in vacuo the tensile strength of the glass should be calculated on the basis that σ has the higher value. Using the values for mica, as determined by Obrimow, the tensile strength determined in vacuo should be about

$$\sqrt{\frac{4500}{375}} = 3.5 \text{ times higher than that in air.}$$

7. The influence of a surface layer prestressed under compression. It was pointed out in the introduction that the heat treatment of a glass may cause appreciable changes in its strength properties. A glass which has been chilled from temperatures above the softening range has a different constitution than the well annealed glass. Without discussing details we can safely say that the average interatomic distances of the chilled glass are greater than those of the same glass after annealing, because the density of the chilled glass is lower. One might expect, therefore, that the chilled glass is mechanically weaker, because its atoms are further apart, and thus a smaller force should be sufficient to overcome the interatomic attraction. In most cases, however, the opposite has been found to be true. The explanation of this behavior is based on the phenomenon discussed in previous paragraphs. Fracture of a glass starts at the surface, beginning with the widening of crevices under tension. Tensile strength values can be raised considerably

(*Continued on page* 50)

Gunite's Standard Grade A for Guide Rings



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SOLVAY TO CONSTRUCT RESEARCH LABORATORY

Construction of a new research laboratory at Syracuse is the plan of the Solvay Process Company, a subsidiary of Allied Chemical & Dye Corporation, according to a recent announcement.

The new Syracuse laboratory will house the research organization of the Alkali Division of Solvay. The laboratory of the Nitrogen Division is located at Hopewell, Virginia.

The construction of this new laboratory and the company's plan to expand its research program and organization is in anticipation of the severe competitive conditions in the chemical industry which they expect to become more intense in the postwar period. The company believes that productive research is the best method of successfully meeting such competition.

AGA AT NATIONAL METAL EXPOSITION

The American Gas Association and The East Ohio Gas Company are jointly sponsoring The Industrial Gas Center at the National Metal Exposition and Congress which will be held in Cleveland's public auditorium, February 4 to 8, 1946.

At the various meetings held during the week of the show, papers will be delivered expounding new ideas and developments in industrial gas utilization. New equipment and new processes will also be discussed.

• J. C. Waterman, recently released from the Army, has returned to his position as manager of the Hammond branch of the Pittsburgh Plate Glass Company. Mr. Waterman was appointed manager at Hammond in 1939.

MECHANICAL STRENGTH OF GLASS . . .

(*Continued from page* 49)

if the influence of these surface flaws can be eliminated. It is known that etching the glass surface with diluted hydrofluoric acid increases the strength values because it rounds the sharp edges of the surface flaws. Another more permanent remedy is to prestress the surface under compression and one way to do so is "toughening" the glass through chilling. J. T. Littleton[40] used this method to eliminate the weakness of the glass surfaces. In a later chapter we will discuss the methods to produce prestressed surface layers in more detail. For the moment it might be sufficient to say that a prestressed surface layer prevents the propagation of a molecular crack and thus eliminates the first slow part of the breaking process.

In a discussion of the experimental work of H. Schardin and W. Struth[27] on the speed of propagation of a crack, A. Smekal[41] remarked that the initial propagation of the fracture of a prestressed glass plate caused by a rifle bullet is limited to the zone of tension and does not penetrate into the surface layer. This explains the well known phenomenon that a sheet of toughened glass when hit may break into innumerable pieces which still stick together despite the layer of air which penetrates the crack system instantaneously.

THE WELDING OF GLASS TO METAL . . .

(*Continued from page 46*)

Contraction of Glass and Metal

The effective strength of the joint varies somewhat with the area of the joint, apparently because of the weakening effect of strains engendered by the differential contractions of the glass and the metal during cooling after soldering. With soldered areas up to about ¾ of an inch in diameter, a strength as great as 1,000 lbs. per square inch of soldered area has been found: as the area increases in size the effective strength diminishes to about 200 lbs. per square inch at a diameter of 3 inches. It is therefore wise to make the joint with one or more relatively small areas of soldering.

It is possible that sprayed metal coatings may prove useful in making reflectors and in decorating glassware. The reflectivity of the sprayed aluminum, as seen through the glass, is roughly from 55 per cent to 70 per cent; and, although this is less than that of ordinary silvering, the superior durability of the coat, especially in its resistance to high temperature, may give it real specific usefulness.

A final word of caution—aluminum owes its resistance to corrosion to the fine transparent but durable film of oxide that forms upon its surface. As electrical engineers know, a solution of common salt attacks the oxide film, and for this reason sprayed aluminum coatings, or soldered joints made as described above, will fail if exposed to sea spray. Otherwise tests indicate great durability. Fig. 2 is a drawing of an experimental sample plate which has been made up to indicate a possible sphere of usefulness for the spraying-and-soldering method when its development has been completed, and the problems of durability have been solved. All the fittings shown have been attached to the "Armorplate" back plate by spraying-and-soldering, without the use of any drilled holes and screws.

CHARLES WALKER OF LANCASTER IRON WORKS DIES

It has been made known by Lancaster Iron Works, Inc. that Charles E. Walker died on November 11.

Mr. Walker was Field Engineer for the company's Northeastern territory, and was a member of the firm for many years.

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